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THE NOMENCLATURE OF FELDSPATHIC GRANOLITES.[1]

Most petrographers agree that the classification of granular rocks, if not of lavas, should be based on mineral composition. This resolves itself practically into the molecular composition. When we state that a rock is composed of quartz, mica, and orthoclase in certain definite proportions, we state the relative proportions of the molecules of which these minerals are composed, and this is true of all other minerals which are made up of a single molecule. But when we introduce terms such as plagioclase, which is composed of two molecules in ever varying proportions, we no longer treat of molecules as such, but of mixtures of molecules. It seems quite clear that the molecular method should be applied throughout, when practicable, and in calculating the composition of the feldspathic rocks the plagioclase should be resolved into the constituent albite[2] and anorthite molecules, and the term *plagioclase* should not be used. This is particularly necessary with monzonites and diorites, for it is clear that if we define typical monzonite as a rock composed of equal quantities of orthoclase and soda-lime feldspar, we may

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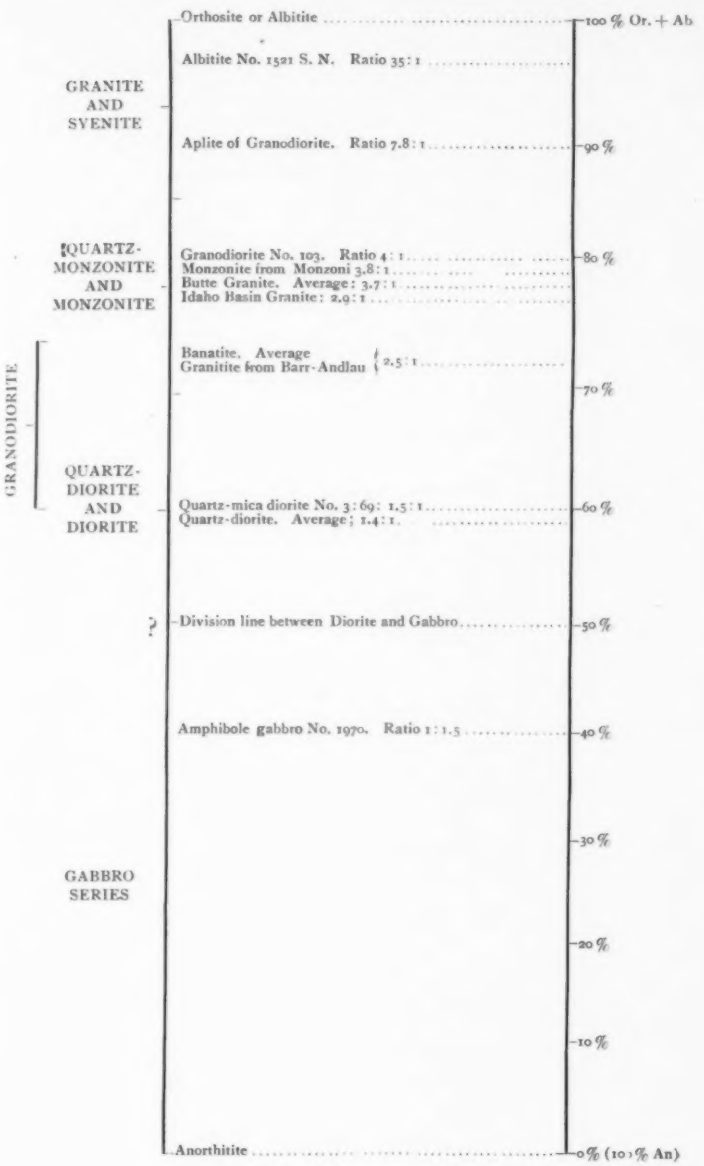
[2] We may treat the soda of the feldspars all as in albite, although some of it may be in the orthoclase.

have orthoclase with basic labradorite, although that must be rare, or, orthoclase with acid oligoclase. The nature of these two rocks would be so different as certainly to make us hesitate to designate them by the same name. In the feldspathic rocks it seems to me proper to base the classification of these rocks primarily on the feldspars, and if we subdivide the feldspathic rocks on the basis of the ratio of the alkali-feldspar molecules (Or + Ab) to the lime-feldspar molecules (An), the true mineral and, to some extent, the chemical relations of the rocks will be brought out, and I think more correctly classify them than to put the orthoclase, or the alkali-feldspars in apposition to the albite and anorthite molecules combined. In order to graphically represent the position of the various rocks under discussion there is now introduced a table which is self-explanatory. In the column represented in the table we have at one end of the series an alkali-feldspar molecule and at the other end a lime-feldspar molecule, and the feldspars of rocks may be said to be composed of one of these molecules or of isomorphous mixtures of the same. The rocks at the head of the column containing feldspars composed chiefly of orthoclase and albite may be designated as orthosite (from the French term orthose = orthoclase) when orthoclase chiefly is present; as anorthosite,[3] when anorthoclase chiefly is present, and as albitite when albite chiefly is present. The rock at the foot of the column, whose feldspathic constituent is largely anorthite, may be designated anorthitite.

It is impracticable at the present time, and, for the purpose of this paper, unnecessary to consider the position in this column of all the feldspathic granolites; a sufficient number, however, are introduced to show the result of the method here proposed, as follows:

Albitite-porphyry or *soda-syenite-porphyry*. — No. 1521 Sierra Nevada. Turner. Seventeenth Ann. Rept. U. S. Geol. Surv., Part I, p. 727. Composed

[3] The use of this term will be at once objected to by petrographers since it has already been used for rocks composed largely of labradorite and more basic feldspars. It is a question, however, since the term in this sense is a misnomer, if it would not be well to drop it.


Orthosite or Albitite
100 % Or. + Ab
Albitite No. 1521 S. N. Ratio 35 : 1
GRANITE AND SVENITE
Aplite of Granodiorite. Ratio 7.8 : 1
90 %
QUARTZ-MONZONITE AND MONZONITE
Granodiorite No. 103. Ratio 4 : 1
Monzonite from Monzoni 3.8 : 1
Butte Granite. Average: 3.7 : 1
Idaho Basin Granite: 2.9 : 1
80 %
GRANODIORITE
Banatite. Average
Granitite from Barr-Andlau
2.5 : 1
70 %
QUARTZ-DIORITE AND DIORITE
Quartz-mica diorite No. 3: 69: 1.5 : 1
Quartz-diorite. Average; 1.4 : 1.
60 %
?
Division line between Diorite and Gabbro
50 %
Amphibole gabbro No. 1970. Ratio 1 : 1.5
40 %
30 %
GABBRO SERIES
20 %
10 %
Anorthitite
0 % (100 % An)

chiefly of albite with some aegerite (?). Ratio of the orthoclase and albite molecules combined, to the anorthite molecules, 35 : 1.

Aplite.—Average of two analyses of aplites from dikes in the Sierra Nevada granodiorites. Composed of quartz> orthoclase> albite> anorthite. JOUR. GEOL., Vol. VII, 1899, p. 160. Ratio, 7.8 : 1. This is the most alkali rich granite in the Sierra Nevada. The amounts of feldspars here given are the result of a more exact calculation, and differ somewhat from the amounts given in the paper referred to. The biotite-granite of my former paper is in reality a quartz-monzonite, and its molecular composition likewise requires some revision.

Granodiorite.—Lindgren. No. 103, Pyramid Peak. Amer. Jour. Sci., Vol. III, April 1897, pp. 306 and 310. Ratio, 4 : 1. Composed of orthoclase> quartz> albite> anorthite.

Monzonite.—Brögger, from Monzoni, described by him on page 24 of "Die Eruptionsfolge der triadischen Eruptivgesteine bei Predazzo in Südtyrol," with a ratio of 3.8 : 1. Composed of orthoclase> albite> pyroxene> anorthite> lepidomelane> hornblende> magnetite> quartz> apatite, zircon, etc. This is taken as Brögger's typical monzonite.

Butte-granite or *quartz-monzonite.*—Weed. JOUR. GEOL., Vol. VII, 1899, pp. 739 and 744. Average of four analyses of the granitic rock at Butte, Montana. Ratio, 3.7 : 1. Composed of quartz> albite> orthoclase> hornblende> anorthite> biotite, titanite, and apatite.

Idaho Basin granite.—Lindgren. Eighteenth Ann. Rept. U. S. Geol. Surv., Part III, pp. 640–641. Ratio, 2.9 : 1. Composed of albite> quartz> anorthite> orthoclase> hyalophane, apatite, titanite, magnetite, and calcite.

Banatite.—Brögger. Average of analyses of five banatites. JOUR. GEOL., Vol. VII, p. 149. The potash and soda given in the paper referred to are interchanged in both the average of the banatites and of the adamellites. Ratio, 2.5 : 1. Calculation approximate.

Granitite.—From Barr-Andlau. Rosenbusch. Die Steiger-Schiefer. Abhandlungen zur geologischen Specialkarte von Elsass-Lothringen, Vol. I, pp. 147–148. Ratio, 2.5 : 1. This appears to be the rock referred to by Brögger on page 62 of his paper on the Monzoni rocks. He states that it contains 35.5 per cent. of orthoclase; 31.5 per cent. plagioclase (Ab_2 An_3); 24 per cent. quartz; and 10 per cent. magnesia-mica. Rosenbusch, however, in the paper above referred to states that this granitite contains about 27 per cent. orthoclase, 40 per cent. plagioclase, 24 per cent. quartz, and 10 per cent. magnesia-mica. The rock represented in the table below, therefore, is Rosenbusch's Barr-Andlau rock, and not the rock discussed by Brögger on page 62 of his paper.

Quartz-mica-diorite or *basic granodiorite.*—Turner. Seventeenth Ann. Rept. U. S. Geol. Surv., Part I, p. 724. Rocks of this type are to be found

ALKALI AND LIME CONTENTS OF FELDSPATHIC GRANOLITES.

Name following new scheme	Albitite-porphyry	Granite or Aplite	Quartz-monzonites and monzonites						Quartz-diorite		Amphibole-gabbro
Original name of author.....	Albitite-porphyry, No. 1521 Turner	Aplite Turner	Granodiorite No. 103 Lindgren	Monzonite from Monzoni Brögger	Butte granite average Weed	Idaho Basin granite Lindgren	Banatite, average Brögger	Granitite Barr-Andlau Rosenbusch	Quartz-mica diorite, No. 369 Turner	Quartz-diorite average Turner	Amphibole-gabbro, No. 1970 Turner
K_2O.....	.10	5.40	3.66	4.42	4.11	3.02	3.48	4.54	1.76	2.01	.22
N_2O.....	11.50	2.74	3.47	3.07	2.76	3.57	3.57	2.46	3.49	3.07	2.75
CaO.....	.55	1.49	3.60	8.50	4.20	3.85	4.15	3.81	5.49	6.00	13.02

PERCENTAGE WEIGHTS OF THE FELDSPAR MOLECULES AND THEIR RATIOS.

Orthoclase...	.56	31.41	17.75	30.00	19.88	10.06	20.57	26.98	10.01	11.12	1.28
Albite.....	96.94	23.16	29.41	19.20	22.98	30.25	29.87	20.94	28.34	25.68	22.53
	97.50	54.57	47.16	49.20	42.86	40.31	50.44	47.92	38.35	36.80	23.81
Anorthite....	2.78	7.00	11.91	12.80	11.48	13.88	20.57	19.04	25.02	27.80	36.58
Ratio of Or + Ab : An.	35 : 1	7.8 : 1	4 : 1	3.8 : 1	3.7 : 1	2.9 : 1	2.5 : 1	2.5 : 1	1.5 : 1	1.4 : 1	1 : 1.5

at a great number of points in the granodiorite areas of the Sierra Nevada. Ratio, 1.5 : 1. Composed of albite> anorthite> quartz> orthoclase><biotite, amphibole, etc. Calculation approximate.

Quartz-diorite.— Turner. Average of five analyses of quartz-diorite from the Sierra Nevada. JOUR. GEOL., Vol. VII, 1899, p. 149. Ratio, 1.4 : 1. Composed of anorthite> albite> quartz> = orthoclase. In most of the quartz-diorites there are biotite, hornblende, and accessory minerals present. Calculation approximate.

Amphibole-gabbro.— No. 1970 Sierra Nevada. Turner. Am. Jour. Sci. Vol. VII, 1899, p. 297. Ratio, 1 : 1.5. Composed of amphibole> anorthite> albite> orthoclase. There are also present magnetite, pyrite, and pyrrhotite. Calculation approximate.

Taking the monozite from Monzoni as a typical mozonite with a ratio of $(Or + Ab)_{3.8} : An_1$ it is clear that if we accept the method here proposed the granodiorite No. 103, the Butte granite, and the Idaho Basin granite are properly quartz-monzonites. If we likewise place the banatites with quartz-monzonites, then the granitite from Barr-Andlau, and many of the granodiorites of the Sierra Nevada will likewise be quartz-monzonites.

The use of mineralogical terms in naming granolites of simple composition seems to me very desirable, although it is not practicable with rocks of complex composition. This can be done with most feldspathic types as follows:

Orthosite	composed	chiefly	of orthoclase
Anorthosite	"	"	" anorthoclase
Albitite	"	"	" albite
Oligosite	"	"	" oligoclase
Andesinite	"	"	" andesine
Labradite	"	"	" labradorite
Anorthitite	"	"	" anorthite

By the addition of abundant and essential quartz to the above ingredients we have appropriate names for the quartz-granolites as follows: quartz-orthosite or granite in its restricted use, quartz-andesinite, quartz-labradite, etc. In all the above cases the quartz is an essential and not an accessory ingredient. When accessory constituents are used in naming rocks the word

should, it seems to me, have the adjective form, as *quartziferous syenite* for a syenite containing some quartz. If such a scheme came into general use the term *granite* would still be a useful one for nearly all quartz-feldspar rocks, in which sense it is used by Michel Lévy and by many other geologists.

H. W. Turner.

THE GEOLOGY OF THE WHITE SANDS OF NEW MEXICO

EAST of the San Andreas and Organ mountains of New Mexico is an extensive valley that has been the subject of much discussion from the practical as well as the theoretical point of view. The writer is not aware that any competent geologist has had the opportunity to make an exhaustive study of its unique features and ventures to put on record the results of a somewhat careful if cursory examination of the valley and its environs.

Our first visit was made by wagon from Socorro, the seat of the county of the same name, by a route which afforded ample opportunity to observe the varied geological conditions of the region to the north and east. East of the Rio Grande, after leaving the immediate valley of the river, the Tertiary red marls are encountered, and lie in rather low terraces upon the foot of the greatly disturbed red beds of Permian and Triassic age. These beds are tilted and greatly faulted, leaving one in doubt as to the sequence at this point, especially as there are curious beds of fire clay and shale filled with a varied flora of carboniferous habit consisting of numerous species of Lepidodendrids as yet not worked out specifically.

The lower part of the Permian is composed of limestones and sandstones capped by anhydride and gypsum beds, the former being in some places massive and upwards of fifty feet thick. Extensive exposures of what is apparently carboniferous limestone constitute the principal axis of the low range at this point, and are followed by the red beds over a large area on the eastern side. These beds, as everywhere in the territory, are impregnated with salt and saline alkalis as well as gypsum. The springs are nearly always salty, and lower flats are covered with "alkali." Passing southward, in the immediate valley of the Rio Grande, near San Antonio, is the remarkable basin of

so-called tripoli described by the writer some years since. There is no reason to alter the opinion then expressed that this fine-grained scale-like deposit is the result of the attrition of the floating pumice which forms the surface of the deposit. In fact, in several other places in the Rio Grande valley similar beds on a smaller scale have been encountered, and in each case the material could be traced directly to the acid scoria of the period of trachite eruption.

To the southeast we pass to the celebrated Carthage coal belt, at which point a collection of Cretaceous fossils was made, but, as they were not found in immediate connection with the coal beds, it is impossible to decide what is the age of the coal upon that basis alone. However, a little farther south in the vicinity of Engle and East of the Caballo Mountains fossils of the Laramie age seem to prove that the coal fields at this point are of that period.

At San Marcial and at frequent intervals down the valley are basaltic cones which have broken through the Tertiary gravels and marls and supplied the material for the sheets of lava so characteristic of the entire territory. It is easy to see that they follow in a general way axes of weakness extending north and south, but it is not so easy to determine the reason for a sudden return to highly basic conditions after a gradual increase in acidity in the volcanic flows of the territory. As the writer has shown in several papers, the sequence is from an augite-andesite or diabase through trachite and pitchstone and obsidian to rhyolite. The soda-syenite and phonolite may perhaps form a transition from the andesite, though the occurrence of the soda series is less general

It suggests itself to the writer that the serial arrangement is to be attributed to an invasion of the silicious crust by the internal heat, and that progressively less of the deeper material was involved in these flows until it may be said that that chapter of igneous activity was closed by the rhyolite eruptions. Long after, perhaps as a result of the differential strain of glaciation and its attendant shifting of the axes of rigidity of the crust,

deep crevices were formed entirely through the acid crust and permitted a slow and relatively quiet overflow. This method of eruption would account for a considerable degree of fluidity of the lava and for the very slight surface disturbance. However this may be, the flows of lava, usually of slight thickness, are often of enormous extent, and where water has had access to the loose materials beneath, the characteristic *mal pais* results.

Our way is now across the Jornado del Muerto, the perils of passage being greatly reduced by the sinking of wells for ranches at various places, though the terrors of a blizzard on these barren treeless plains needs but to be experienced to be appreciated. Though comparatively arid and seemingly barren, the short grass furnishes a good subsistence to many herds of both cattle and horses.

Rising by a rather moderate slope from the plain are the foothills of the great range which begins with the Sandias east of Albuquerque and is continued in a broken line by the Manzanos, the Oscuros, the San Andreas, and the Organs. In the Sandias and Manzanos the granite, everywhere lying at the base of the stratified rocks, so far as known, in the territory, is exposed in an extensive escarpment on the east side of a very important fault line and the superincumbent stratified rocks dip rapidly to the east. In both the ranges mentioned the rock lying upon the granite, or its gneissic or schistose equivalent, is a quartzite whose materials seem not to have been derived from the subjacent granite, but from a schist or quartz rock which we suppose to have been the superficial portion of that series. The age of the quartzite, as well as that of the granite, must at present remain a matter of conjecture in spite of poorly preserved fossils in the limestone layers found in one or two instances in the midst of the granite. Reposing on the quartzite conformably in the Sandia and Manzano ranges is a silicious series with a few limestone bands whose fossils seem to be of undoubted Coal Measure age. This is followed by a dark conchoidal limestone with shales having a fauna similar to that of the Upper Coal Measures in Ohio as will be more particularly set forth in another

place. The lower series we have called the Sandia series from the place where best seen. Some distance above the dark lime is a sandstone or conglomerate which is rather inconstant in thickness and may be absent, but which roughly marks the transition to the permo-carboniferous as generally developed in all the ranges under consideration. This Coyote sandstone is particularly well seen in the canyon of that name in the south end of the Sandias. Above this is the large series of massive gray and silicious lime at whose base it is usual to find a large form of Fusulina and, a little higher up, a well defined zone characterized by the bryozoa preserved on the faces of the cleavage slabs. Here begin the evidences of a transition to the Permian as indicated by the presence of *Mekella striatocostata*, *Terebratula bovidens*, *Productus punctatus*, and a variety of forms which are mingled with fossils also found in the carboniferous below. At the top of the gray lime is a large series of coarse, red quartzites and sandstones interbedded with dark earthy limestones and shales. There are few fossils except petrified wood and the few found still preserve a carboniferous habitus. This Manzano series is everywhere in evidence where a sufficiently high horizon is reached but is often removed from the crests of the range while it occurs in the eastern faulted extension. Following this is the group of red quartzites, sandstones, shales, and marls which we have recognized as the equivalent of the "red series" of Texas and Kansas. Three divisions can be made out in all parts of the territory examined which have been named from their prevailing or characteristic color, though it is not to be supposed that the color mentioned is constant. The lower or "red bed" division still retains some bands of limestone or lime breccias, the latter being a very characteristic element. Some 500 feet may be estimated as the average thickness of this division and prior to the work recently done in the valley of the white sands we had no definite evidence as to the age of the entire division. We only knew that a narrow bed of quartzite near the base at a point east of the Sandia Mountains contained the well-known Permian forms such as *Bakvellia parva*, *Myalina attenuata*, *Pleurophorus*

subcuneatus, etc. The major portion of the series proved obstinately barren. At the top of this division there are found in the most widely distant parts of the territory enormous deposits of gypsum and salt. In fact the presence of salines may be said to characterize the series, but especially at the passage from the red into the chocolate beds above it. The chocolate series has a thickness of at least 600 feet and passes through quartzites and gray and red sandstone layers into the loose vermilion marls and clays of the upper division. So far, we have no positive evidence as to the age of the two upper divisions, but may presume the chocolate beds to be Triassic and the vermilion division to represent whatever of Jurassic time is accounted for in the territory or at least in the central portion.[1]

South of the Manzano range the continuity of the uplift is broken so that in the Fra Cristobal and Caballo mountains near the Rio Grande and in the Oscuro range farther east the dip is, as in the Sandias and Manzanos, to the east while in the San Andreas, occupying an intermediate position farther south, the dip is to the west so that the high escarpment with its granite and schistose base faces the great salt plain.

In the interval between the range bordering the river and the Oscuro Mountains we have abundant evidence of the existence of the Cretaceous with its lignitic coals and it may be assumed that the Cretaceous also extends southward on the west side of the San Andreas, though nowhere exposed in the *Jornardo del Muerto*. Passing eastward lower horizons gradually emerge till, as we enter the interval between the north end of the Andreas and the south end of the Oscuros, the red beds are seen in the form of low hills with a dip to the east at the western foot of the Oscuros. Underneath is a part of the Permo-carboniferous. It appears, therefore, that the Oscuro range is separated by a fault line from the axis of the Andreas. On the west side of the San Andreas the red beds are represented as is shown by the extensive deposits of calcium anhydride in the foothills.

[1] It will be remembered that Professor Cope in 1875 identified part of this series as Triassic and that Dr. Newberry described Triassic plants from New Mexico.

The eastern escarpment of the Andreas is bold and irregular in the extreme but the fault which created it seems to have been wavy so that a crenulated or sinuous aspect is presented to the plain. The granite in some instances seems to have escaped in pinnacled or columnar form and throws off the restraining influence of the stratified rock to appear in jagged peaks. This is particularly true in the Organ Mountains where, however, there must be added the influence of a later trachytic overflow. Our examination of the San Andreas was cursory but was sufficient to show that the thickness of the stratified series is greater than in the Sandias and Manzanos. The lower portion is composed of quartzites and silicious shales which may be compared with the quartzites in the Manzanos. Above this is a large series of gray cherty limestones and quartzites of an entirely different texture and appearance. This has baffled our search for fossils in the Andreas and the Caballos where it is also well developed but, fortunately, we have been able to discover in the upper part of this series on the eastern side of the salt plain fossiliferous bands which place the age beyond doubt. Spirifer Grimesi, Leptaena rhomboidalis and other well-known Burlington brachiopods are associated with crinoids of that period in great abundance. Some of the bands are practically composed of the débris of the crinoids.

Above the Burlington there seems to be a hiatus, for the next species encountered are distinctively Coal Measure forms and the sequence from this on to the top is as in the ranges farther north though there seems to be a tendency for the limestone to encroach on the sandy elements and for the individual components to thicken toward the south, a fact which we interpret as indicating deep-sea conditions.

Attention has elsewhere been called to the method of occurrence of the copper found so widely scattered through these ranges. It was shown that the deposits of copper which have attracted so much attention were formed in veins that extend from top to bottom of the sedimentary series but do not seem to cut the granite, at least to any depth or with any regularity.

These veins are so regular that it is conceived that they may be best explained as the result of warping or shrinking in the sedimentary series and it seems certain that they have been filled from above. The vein matter is chiefly calcite, fluor spar, siderite and barite and it is chiefly at the intersection of the vein with a band of iron-filled quartzite, reposing on the granite and forming a definite selvedge to the sedimentary series, that the copper is deposited. The ores include nearly all the common copper compounds, calchocite, malachite, azurite, bournite and cuprite predominating. Here, as in Hannover and Santa Rita, it seems indubitable that the iron, accumulated by leaching, has been the agent in precipitating the copper.

Between the Organ and San Andreas mountains there is an area on either side where the granite is laid bare and it is true that some show of copper may be found in crevices and basins superficially on the granite. It is probable that all, or a great part, of the copper of the two ranges has been originally derived from the red-bed series (Permian and Triassic) by infiltration, for the original existence of the cupriferous series on top of the strata now remaining in the ranges is indubitable. Dikes of diorite cutting through the granite and sedimentaries along or near the fault line have caused portions of the latter to lie in irregular fragments along the foot of the escarpment to the east, the strata dipping towards the dike which served to pry them from their original position.

Standing upon a jutting eminence of the San Andreas and turning eastward one looks out upon a scene difficult to parallel. At one's feet is an enormous plain, apparently as level as a floor, over forty miles wide and extending as far as eye can reach to north and south. On the southern horizon rise the Jarillas Mountains which only partially interrupt the plain, while to the northeast are the snow-capped peaks of the Sierra Blanca. Northward the plain is narrowed by the eastward intrusion of the Oscuro range while it is possible to make out the dark area of basalt which covers that part of the plain to the east and southeast of that range. This is the widely-know "*mal pais*" of

Socorro county which has proven such an effectual barrier to communication between the Rio Grande valley and the growing region of White Oaks. South of the *mal pais* is a great white sea on which one can fancy the glint of white-caps. Such a body of water being out of the question the uninstructed observer would surely think himself the victim of a mirage but we recognize in the snowy area the famous white sands. Curious and conflicting stories are current respecting the area but the truth is not less interesting. We had already been forced to the conclusion that the true origin of the saline and gypsum beds is to be sought in the red series above mentioned. It seemed at first, however, that the geological relations would prove baffling.

Rising abruptly from the level plain on its eastern side are the foothills of the Sacramento range near which pass the trains upon the newly-finished El Paso and Northeastern railway. The escarpment is nearly perpendicular and the dip is very slight and to the east. The bottom of the sedimentary series is not reached, at least in this vicinity, but it is evident from a comparison of this with the western escarpment that the base is not far distant. The section is given in detail below but we were very fortunate in coming upon a locality where the lower portion of the section is fossiliferous About 560 feet from the base, at Dog Canyon, some 12 miles southeast of Alamogordo is a band of crinoidal limestone which, together with the gray lime and quartzite above it, contains numerous, though poorly preserved fossils. Among these enough forms were identified to determine the limestone as Burlington. As nearly as we could determine the Burlington is represented by at least 250 feet. Several intercallary sheets of igneous rock (diorite, with porphyritic hornblende) penetrate the strata and obviously connect with a boss farther east and higher up the canyon. The influence of the intrusive may account for the amount of chert seggregated in this portion of the section but, for whatever cause, the limes are chiefly highly silicious and quartzite has replaced former limestones. Above the Burlington, which is entirely absent farther north, is the entire series of Coal Measure

limestone and sandstone as seen in the Sandia range except that the deeper sea conditions have expressed themselves in greater thickness of limestone. The fossils in the lower part are of mid-carboniferous types but pass somewhat gradually into the assemblage which we have characterized as Permo-carboniferous. *Meekela*, *Terebratula bovidens*, *Productus punctatus*, a large *Bellerophon* and many other familiar forms indicate an approach to the top. Above the measured escarpment but inaccessible to our reach is a series of what appear to be yellowish sandstones or quartzites which may confidently be referred to the Manzano series at the top of the Permo-carboniferous. Northward the dip rapidly veers to the northeast and thus the several horizons drop below the surface and bring still higher ones than those seen at Dog Canyon within reach. About 16 or 18 miles west of the main escarpment is a low ridge of hills which prove to consist of carboniferous limestone but bearing evidence on their western aspect of the fault which brought the plain down to a lower level. This ridge is most instructive in showing that the fault was not a single break but by steps or successive faults. Wells in the plain to the west all show the existence of the red beds both by the presence of salt (often strong brine), but also by the red color of the marl brought to the surface. North of the outlyer spoken of is a most interesting spring which has built up for itself, geyser-like, a mound of some thirty feet above the general level from which issues a quantity of warm and highly saline water which flows into a depression and, sinking from view, leaves a large salt and alkali flat. Other similar lakes are grouped in the neighborhood. The actual character of the deposit is generally masked by a calcareous marl of white or gray color which forms a crust over the entire plain and is highly charged with salts except at the immediate surface.

But passing northward and observing several other saline springs similar to the one described, the route carries us through the intensely modern "boom" town of Alamagordo with its great sawmills fed from the Sacramento Mountains by a spur railroad and the equally typical old Mexican town of Tularosa

where nearly every house is of adobe. The intense red color of the adobe awakened our curiosity and led us to the examination of the escarpment to the east and north. As we hoped, the dip had sufficed to bring to the general level strata which at Dog Canyon were out of reach and the lower third of the red series with its capping of gypsum and salines is at the foot of the section. The following is the section as casually examined during our visit — a section which will yield a large suite of interesting fossils of decided Permian facies, though well-known carboniferous forms extend throughout. Commencing at the bottom, we have first a poorly exposed series of silicious shales and thin-bedded limestones in which is a characteristic Permian assemblage including *Myalina permiana*, *Myalina attenuata*, *Pseudomonotis hawni*, *Aviculopecten occidentalis*, etc.

Then follow, as we ascend:

Reddish shales and loose sands	15 feet
Limestone	6 "
Greenish sandy shale	10 feet
Coarse conglomerate with pebbles of granite, etc.	5 to 10 "
Purple red sand with pebbles	20 to 25 "
Earthy limestone	2 "
Loose red sand	18 "
Coarse red conglomerate	4 to 5 "
Red sandstone	8 "
Loose red sand and shales	18 "
Conglomerate	4 "
Limestone	2 "
Greenish sand	12 "
Earthy lime shales and sand	5 "
Limestone and calcareous shale	6 "
Sandy shale and green sands	35 to 40 "
Well marked bench of gray lime	8 "
Red shale including a very irregular conglomerate	4 to 8 "
Thin bed of lime	1 foot
Green fissile shale	6 feet
(Gypsiferous marl, probably surface deposit)	00 "
Limestone and shale with numerous small fossils	6 to 8 "
Brown or red shale with numerous fossils	35 "
Sandstone	8 "

Shale	6 feet
Sandstone	6 (?) "
Limestone	1 foot
Green sandstone with calcareous band	20 feet
Calcareous zone	00 "
White sandstone	4 "
Shell limestone fossils	1 foot
Nodular marl	15 feet
Nodular limestone	2 "

Our ascent ended here but beyond appeared the gypsum beds reposing upon red and white marls as in the Nacimiento region and elsewhere. Still above and forming separate terraces are the chocolate and vermilion beds, and at the top of the section the lower Cretaceous. The creeks or arroyos which traverse the gypsiferous horizon come laden with salt which is deposited as a white coating upon their beds and banks.

Having satisfied ourselves both as to the age and the character of the deposits which underlie the great plain, we undertook a study of the plains themselves. At the southern end of the *mal pais* which forms the northern boundary of our field of work, numerous springs gush out from beneath the thin sheet of black basalt. These springs differ from those from the salt valley itself, in that the water is not warm nor appreciably salty. It is apparent that the lava has served to retain the water which, on making its way beneath the sheet, has excavated channels in which the water may be heard rushing by one crossing the lava. One of these streams in particular, at Mal Pais spring, forms a considerable creek which supports a varied plant and animal life including fish of considerable size and several crustaceans (Gammarus or the like). The water, before it flows many rods, becomes distinctly salty and bitter. At a little distance to the south begins an area of depression which is forty miles long and receives the drainage from all directions. This whole area is covered with saline efflorescence while all the shallows, when dry, as they are most of the year, have considerable deposits of salt on the surface and the subsoil or under clays are infiltrated with alkaline salts the nature of which will be fully discussed in another place

About one mile from the Mal Pais spring above mentioned is a small salt lake which has furnished the salt for ranches for a radius of many miles during the historic period and at our visit the surface was covered to the depth of an inch or so with pure crystalline chloride of sodium. Still west and forming the western limit of the visible saline beds, is a drainage arroyo whose source seems to be in the red beds that emerge west of the Oscuro Mountains and conveys their saline water to the basin of the sands. Along the course of this arroyo are numerous salinas and alkali flats and these gradually broaden to form what may be described as one vast alkali and salt plain where brine stands for part of the year. Other arroyos come in from the west in some of which, even at the time of our visit, was a considerable quantity of flowing water which is a strong brine unfit for cattle even when accustomed to drink from the saline springs which unwonted animals will reject. Where these arroyos enter the salt lake and along the shores of the lake are bluffs of erosion some of which are over twenty feet high. In these exposures we encounter the red bed formation with its marls and gypsum deposits. Large quantities of pure crystalline gypsum are here exposed and the marls are alkaline and saline. We have therefore local proof, as well as the most conclusive evidence from the environs, that the whole of the plain is in or near the horizon of gypsum and salt that separates the lower from the middle member of the red or saline series.

In the salt flats the ribs of gypsum rise in successive ridges, and the action of the elements soon breaks up the exposed crystals into small grains which are carried by the winds hither and yon. This characteristic of the salinas accounts for the most curious and notable of the many peculiarities of these plains, namely the white sands. These have been attributed to the action of springs and the material has been supposed to have crystallized from solution. It has been suggested that the sands have been collected by floods, but a short examination shows that these great drifts are simply sand dunes collected from the gypsum sand formed as above stated on the surfaces of the lakes. The salt

and alkaline salts are also driven with the gypsum but on account of their solubility they do not remain in the dunes. These dunes lie to the south and east of the flats whither they are driven by the prevailing winds and not only cover a large part of the salinas themselves, but form a growing fringe to the east and south. The dunes are, in the majority of instances, very pure gypsum though there is a small commingling of earthy impurities. The soil underneath is impregnated with salt and soda and salt lakes are scattered over the area covered by the dunes. The intervals between the crests of the ridges support a scanty but very interesting vegetation. Near the southeastern angle of the sands is a very important salt lake which has been known as a source of salt for the ranches for many years. The north and south extent of the "white sands" is about 35 miles while the greatest breadth at the southern margin is about 18 miles. The lines connecting the extreme points are irregular, enclosing roughly a triangle of about 350 square miles. To this may be added nearly as much more of saline land on the west and in isolated areas to the south. The whole plain is geologically of the same nature, but, inasmuch as it is either higher than the basin or is more completely drained (to the south), the saline ingredients are not brought to the surface.

East of the Jarillas Mountains this plain again gives external evidence of its subterranean supply of salines while far to the north, beyond the covering of lava, there are depressions of the same character and of the same geological age and nature. The fact that such depressions occur in New Mexico only in connection with the red beds leads to a suggestion that may be worthy of consideration. It is evident to anyone who has studied the geology and geography of the territory that it is, as Major Powell said long ago, the best drained region in the world. The comparative newness and permeableness of its strata all militate against the formation of local basins. There has been no glaciation to produce local lake reservoirs. Erosion has kept well in advance of secular changes of level and barriers of local origin do not prove capable of retaining the waters which come in

torrential plentitude when they come at all. Some explanation must be sought for the basins found in the saline areas. It might be supposed that such explanation would be found in the depressions resulting from the post-Tertiary lava flows which occur over the entire territory. To this it may be replied that the basalt is certainly of deep origin, for the preceding flows were all acid and the basalt overflows are essentially similar among themselves and demand a common origin at a depth. Moreover the distribution of the flows indicates that the orographic lines of weakness opened were of almost continental extent. The depressions due to the outflow of basalt would not account for the local basins referred to and we are driven to the conclusion that these slight depressions are due to the effect of the removal of the soluble ingredients in these beds themselves.

The discussion of the economic aspects of these beds will occur in the forthcoming bulletin of the University Geological Survey of New Mexico.

C. L. HERRICK.

DESCRIPTION OF PLATES

PLATE I.

Sketch map of the region of the "White Sands" including part of Dona Ana, Socorro, and Otero counties, New Mexico.

PLATE II.

Mostly Permian fossils from exposures near Tularosa and east of the Sandia Mountains in Bernalillo county. These plates are given to illustrate the fauna rather than as a basis for a discussion of the species figured, which have as yet been subjected to no critical study.

FIG. 1 *Pseudomonotis* n. sp. (*costatus*).
FIG. 2. *Bellerophon* sp.
FIG. 3. *Aviculopecten cf. coxanus.*
FIG. 4. *Pseudomonotis radialis* Meek.
FIG. 5. Undetermined.
FIG. 6. Undetermined.
FIGS. 7, 8. *Rhynchonella osagensis* Swallow. Two views.
FIG. 9. *Pleurotomaria cf. subdecussata* Geinitz.
FIG. 10. *Pleurotomaria marcouiana* Geinitz.
FIG. 11. *Rhynchonella* sp. Two views. (*cf. R. osagensis* Swallow).

FIG. 12. *Terebratula ?* sp. Two views.

FIG. 13. *Zaphrentis* sp.

FIG. 14. *Productus cora* D'Orb.

FIG. 15. Portion of the whorl of *Euomphalus* sp.? All the above are from shale number III of the Tularosa section.

FIG. 16. *Bakevellia parva* Meek and Hayden. From base of section near adobe smelter east of Sandia Mountains at the base of the Permian.

FIGS. 17, 18, 19. Undetermined gasteropods from the base of the Tularosa section.

FIG. 20. *Orthoceras* sp. Base of Tularosa section.

FIG. 20 *bis*. (Lower left corner) *Edmondia* sp. Same place as the above.

FIGS. 21, 22, 23. *Meekella striatocostata* Cox. From No. 3, Tularosa section.

FIG. 24. *Myalina permiana*, base of Tularosa section.

FIG. 25. *Bellerophon montfortianis* Norwood and Pratten. Base of section at adobe smelter.

FIGS. 26, 27. *Pleurophorus subcuneatus* Meek and Hayden. Same as the above.

FIG. 28. *Sedgwikia topekaensis* Shum. Shales below upper layers at Tularosa.

PLATE III.

FIG. 1. *Aviculopecten occidentalis* Shum. Left valve.

FIG. 2. *Aviculopecten occidentalis* Shum. Right valve.

FIG. 3. *Pseudomonotis hawni* Meek and Hayden. This and the above from the lowest level of the Tularosa section.

FIG. 4. *Myalina perattenuata* Meek and Hayden. Adobe smelter east of Sandias.

FIG. 5. *Myalina swallovi* Shum. Upper Carboniferous, Sandia Mountains.

FIG. 6. *Discina convexa* Shumard. As above.

FIG. 7. *Gervillia longa* Geinitz. As above.

FIG. 8. *Chonetes granulifera* Owen. As above.

FIGS. 9, 10. Unidentified gasteropod. As above.

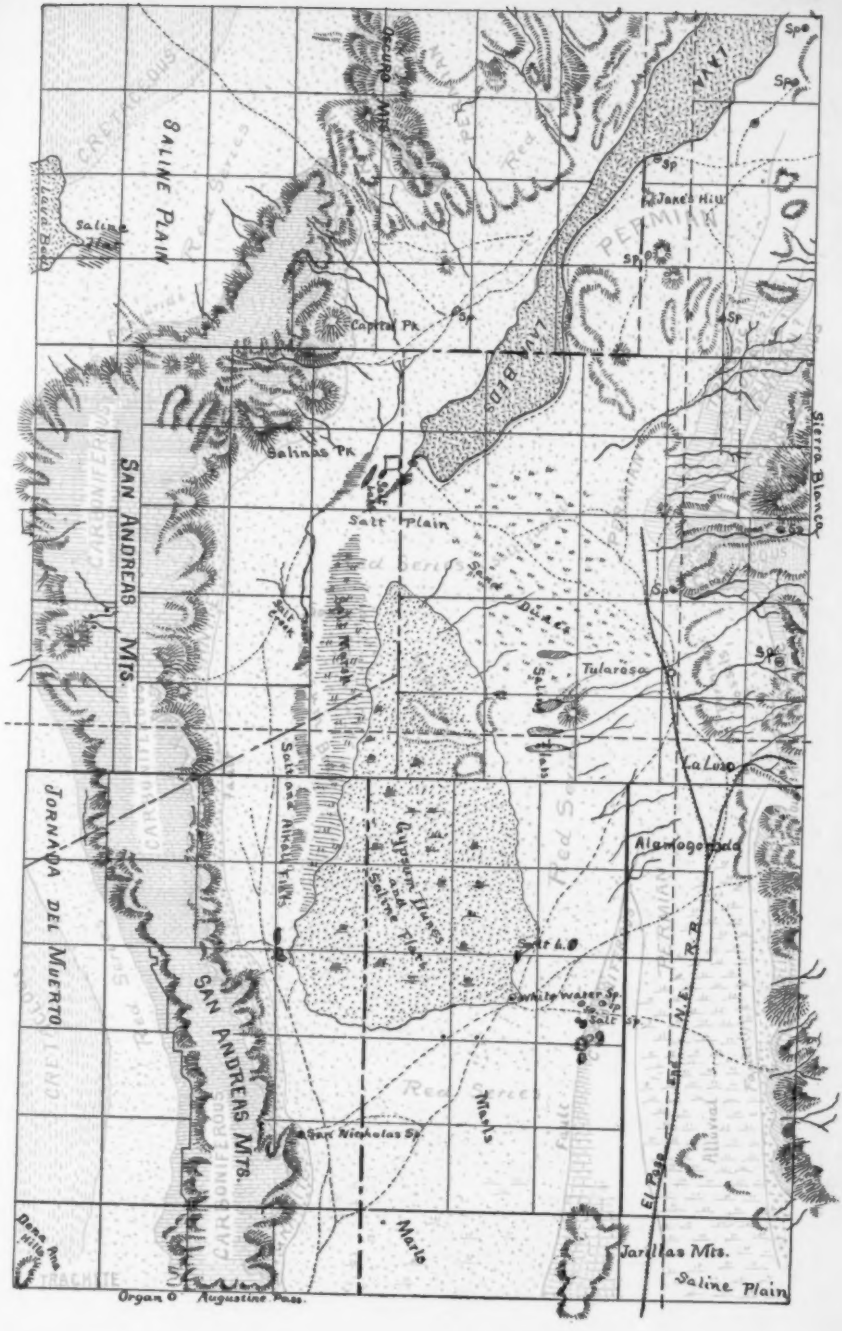
FIG. 11. *Myalina ?* Permo-Carboniferous east side of Sandia Mountains.

FIG. 12. *Edmondia* sp. Base of Permian, adobe smelter.

FIG. 13. *Edmondia aspinwalensis* Meek. Permo-Carboniferous. Jemez Spring.

FIG. 14. Unidentified gasteropod. Upper Carboniferous.

Plate I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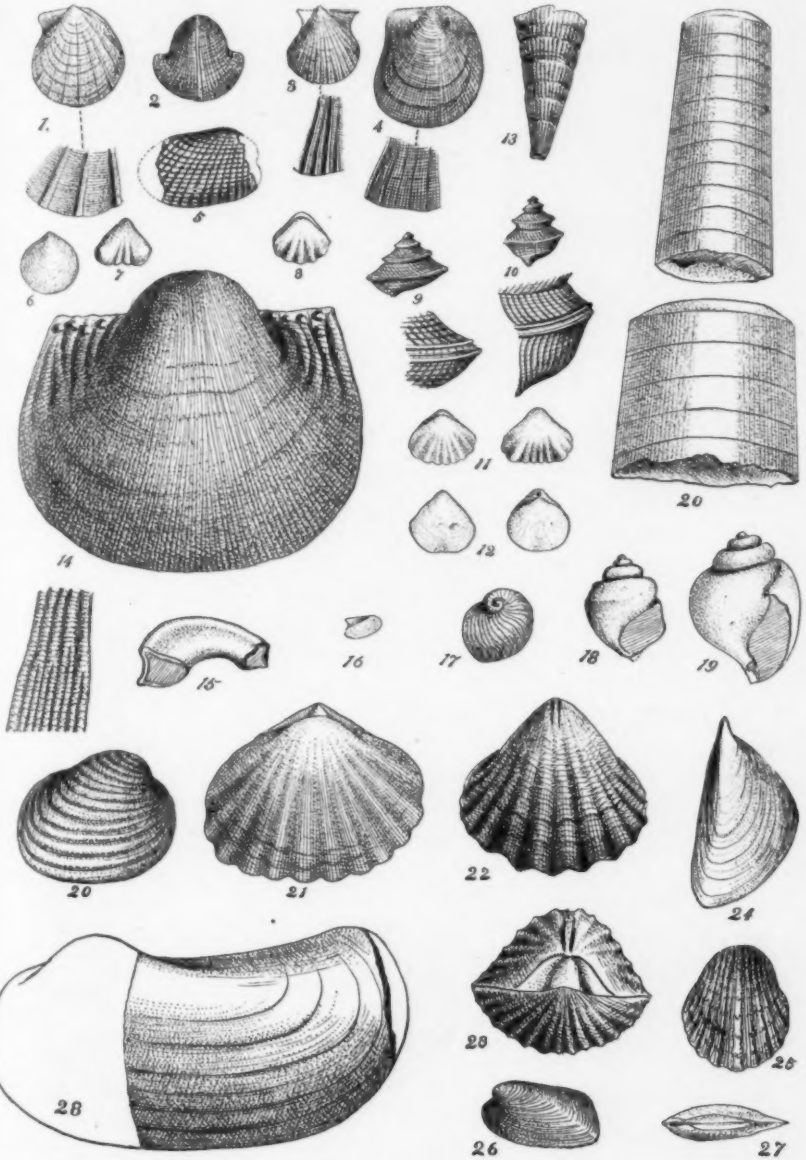
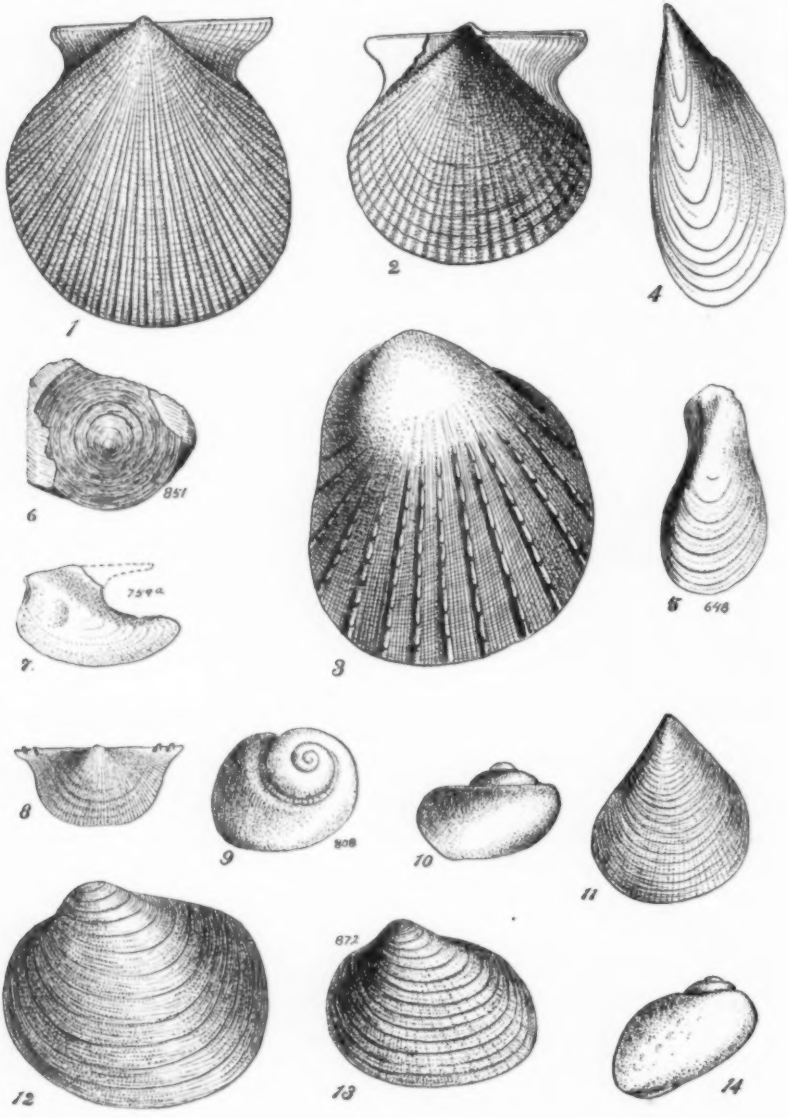
Lava Beds
Salinas Pk.
Capitol Pk.
Lava Beds
Lava
Janes Hill
Sierra Blanca
Salinas Pk.
Salt Plain
San Andreas Mts.
Salt Creek
Tularosa
La Luz
Alamogordo
Jornada del Muerto
Gypsum Dunes and Saline Flats
Salt L.
White water Sp.
Salt Sp.
A.T. & S.F. R.R.
El Paso
San Nicholas Sp.
Marla
Jarillas Mts.
Saline Plain
Organ Mts.
Augustine Pass.

JOUR. GEOL., VOL. VIII, NO. 2 Plate II



JOUR. GEOL., VOL. VIII, NO. 2 Plate III



THE ORIGIN OF NITRATES IN CAVERN EARTHS

MUCH interest has been taken in the great caverns of Virginia, Kentucky, and Indiana by tourists, and considerable popular literature has been published, especially in description of Mammoth, Luray, and Wyandot caves. In this literature rather frequent allusion is made to the "nitrates" in cavern earths, and occasionally a theory is advanced to explain their origin. Popular interest is awakened in this question by the large amount of "saltpeter" known to have been taken from Mammoth Cave during the war of 1812, and from similar caverns in Alabama and Georgia during the Civil War for the manufacture of gunpowder.

The origin of this supply of nitrates is commonly ascribed to animal remains, and especially to the excrement of bats. In Mammoth Cave, however, the cavern earth was worked for nitrate for a distance of over five miles from the only opening known which leads to the surface, while bats as a rule go but a short distance from the entrance of the cavern. Again, on account of the antiseptic character of the atmosphere of caves, we would expect, in case the nitrate was derived from bats, to find some animal remains, in the form of their dried bodies, their bones, or their excrement; but organic matter of any kind is rare in cavern earths. The hypothesis ascribing such an origin to the vast stores of nitrates taken from Mammoth and other caverns seems, therefore, inadequate.

Caves in limestone regions are due to the solvent action of water containing carbon dioxide. This process must have been very slow and in most cases unaided by mechanical erosion, thus leaving the insoluble portion of the limestone as a deposit on the floor of the cavern. This residue is known as cavern earth.

From the mode of formation of caves, it is evident that this residue must have been washed perfectly free from all salts

readily soluble in water by the water which slowly carried away the limestone itself during the formation of the cavern.

Recent progress in bacteriology and agricultural chemistry has thrown much light upon the origin of nitrates in soils by the oxidation of organic matter in the presence of certain bacteria. The surface soil in cavernous regions is usually loose and porous, and consequently favorable both for nitrification of organic nitrogen and for downward percolation of the surface water. It may not be unnatural, then, to ask whether the nitrates in cavern earths may not have orginated wholly or in part from nitrification of organic matter at the surface and the subsequent leaching of the nitrates so formed into the caverns. Caves would thereby act merely as receptacles for the surface drainage, and provide an avenue for the return of the percolating water to the atmosphere by evaporation. If the nitrates in caves originated in this way, we would expect to find also in cavern earths such other soluble constituents of soils as must necessarily have been leached out along with the nitrates.

By leaching cavern earths with cold water some material is always extracted. The amount thus washed out is sometimes as much as 13 per cent. of the sample. The following analyses are given of the soluble matter of cavern earths derived by washing the samples with cold water, the figures representing percentages :

Source	Calcium oxide	Sulphuric anhydride	Alkalis	Chlorine	Nitric acid	Ammonia
Mammoth Cave, Ky.	1.06	2.16	1.45	0.28	0.37	0.005
Mammoth Cave, Ky.	3.20	4.57	3.04	1.41	1.36	0.001
Saltpeter Cave, Ind.	2.31	3.30	2.26	0.23	1.88	0.007

From these results it is seem that nitrates form only a small portion of the total soluble material in cavern earths.

A kilo of subsoil over Mammoth Cave was placed in a percolator, and two liters of water charged with carbon-dioxide were added and allowed to stand for a week, with frequent stirrings, when the water was slowly drawn off. The water was then

evaporated in a platinum dish and the residue was analyzed. A sample of cave earth collected as nearly as possible beneath the spot where the sample of subsoil was taken, was also treated in the same way. A sample of bat guano and one of the earth occurring just below the guano were subjected to the same treatment. The results of these several analyses are given in the following table, the figures representing percentages of the sample taken:

	Mammoth Cave		Dixon's Cave	
	Subsoil over Mammoth Cave	Cave earth below	Bat guano	Earth below bat guano
Sulphuric acid, SO_3	0.0054	4.16	0.67	0.031
Lime, CaO	0.0018	2.03	3.34	0.23
Alkalis, Na_2O, and K_2O	0.00288	2.86	0.37	0.26
Phosphoric acid, P_2O_5	trace	0.0003	0.044	0.0137
Ammonia, NH_3	0.00192	0.011	0.102	0.019
Nitric acid, N_2O_5	0.0068	0.82	6.016	0.0118

By comparing these analyses it is evident that the soluble material in the cave earths might have been leached from the soil above.

The bat guano forms a thin layer over the floor of Dixon's Cave, and is composed of a mixture of excrement and fuzzy material from the bats' bodies, together with sand and earthy matter from the walls of the cavern. Judging from the above analyses, this layer seems to have acted as an excellent absorbent preventing the further percolation downward of material dissolved from the soil above the cave, since the earth below contains very little soluble material.

But guano was found to contain considerable amounts of salts of phosphoric acid soluble in cold water, while the cavern earths proper contain only traces of these salts. The total percentage of phosphate dissolved out of bat guano by dilute acid was found to be about the same as that derived from cave earth by the same treatment. The following results of analyses of bat guano, taken just as it came from the cave, making no attempt to mechanically separate the sand and earthy matters, and of cave

earth, both from Dixon's Cave, were obtained by igniting the dried samples and then treating them with dilute hydrochloric acid.

	Bat guano	Cave earth
Loss on ignition	32.16	6.02
Insoluble residue	40.65	73.80
Soluble silica, SiO_2	1.03	trace
Calcium oxide, CaO	10 95	7.51
Ferric oxide, Fe_2O_3	1.20	3.37
Alumina, Al_2O_3	5.27	2.41
Magnesia, MgO	0.37	0.30
Sulphuric anhydride, SO_3	4.37	2.77
Phosphoric anhydride, P_2O_5	2.62	2.10
Alkalis and loss	2.38	1.72

This sample of cave earth contained no perceptible organic matter.

It seems from a comparison of these analyses that we cannot prove the presence of animal remains by the total content of phosphoric acid soluble in dilute mineral acids, since a residue from limestone must contain considerable calcium phosphate on account of the insolubility in water of this salt of calcium.

Analyses of the water dripping from the roofs of caves were made, and results were obtained which do not vary markedly from results obtained from analyses of ordinary sub-drainage waters. The following is an analysis of the residue from water which dripped from the roof of Mammoth Cave:

	Milligrams per liter
Silica, SiO_2	12.23
Sulphuric Anhydride, SO_3	15.81
Phosphoric Anhydride, P_2O_5	trace
Chlorine	2.71
Ferrous Carbonate, $FeCo_3$	1.02
Calcium Carbonate, $CaCO_3$	53.61
Magnesium Carbonate, $MgCO_3$	7.17
Alkalis, Na_2O and K_2O	16.56
Ammonia, NH_3	0.04
Nitric Acid Anhydride, N_2O_5	5.71

A comparison of the soluble constituents given in this analysis with the soluble material extracted from the cave earth, as

shown in the preceding analyses, points forcibly to the probable origin of these salts in cavern earths.

It was found from analyses of many samples taken from Saltpeter Cave, Indiana, so as to cover practically the whole floor of the cavern from the opening to the end, that nitrates were distributed throughout the entire extent of the dry chamber, irrespective of distance from the entrance. Since bats do not go far inward from the entrance of caves, and since we find no organic matter in cave earth to indicate an animal origin for the nitrate contained therein, it is evident that we cannot regard the nitrates in cavern earths as originating from bat guano.

The conclusion reached from this investigation is that the nitrates in caves were brought in by water percolating through the soils above the caves and were deposited on the floors. Currents of air in and out of the caverns removed the water, and the various salts it previously held in solution were left as an inheritance to the cave earth. A cavern acts, therefore, merely as a receptacle for stopping a portion of the surface drainage. This accumulation of salts occurs only in caverns where the inflow of surface water does not exceed in amount the water removed by evaporation. In wet caves the soluble salts are washed onward with the water bearing them and so are not deposited.

Nitrates found under overhanging cliffs are of a similar origin. Water bearing dissolved nitrates percolates through the soil and finally oozes out at the surface. The water evaporates and leaves behind an incrustation of its soluble materials. The nitrates thus formed under overhanging cliffs remained permanently stored there, being securely protected from rain. They served, along with the nitrates found in the caves of Alabama and Georgia, as a source of saltpeter used by the South during the Civil War for the manufacture of gunpowder.

When vegetable matter is piled up and allowed to decay, an incrustation of potassium nitrate forms on the surface. The vegetable or organic nitrogen has been oxidized to nitric acid. The nitric acid combines with the potash of the plant to form potassium nitrate. The water evaporates from the pile and

leaves its load of nitrate behind as an incrustation on the surface, while water from the interior of the pile works gradually towards the surface to take the place of the water removed by evaporation. Thus the materials soluble in water are slowly brought to the surface and left as a deposit which may be removed mechanically. This is an old method of obtaining saltpeter from manure heaps, and it is even now used to a small extent in Europe. The occurrence of the nitrates in caves as an incrustation on the surface of the cavern earth shows that water has been removed by evaporation in much the same way as from the overhanging cliff and from the compost heap.

We always have nitrogenous matter scattered over the surface of the soil and this decaying vegetation furnishes continuously during its decay a small amount of nitric acid. All nitrates are soluble in water and so are sure to be found in the percolating water. If, then, the percolating water is intercepted and evaporated, the nitrate must be left behind. Nitrates should, therefore, occur in all caves and analyses of the cavern earths of a great number of caves in Indiana and Kentucky demonstrates that the occurrence of nitrates in cavern earths is general. No dry cavern earth was found which did not contain soluble salts of nitric acid, and these salts were distributed uniformly from the entrance to the end of the cavern.

WILLIAM H. HESS.

February 23, 1900.

THE CALCAREOUS CONCRETIONS OF KETTLE POINT, LAMBTON COUNTY, ONTARIO

It cannot be said that the mechanics of the concretionary process in sedimentary rocks is well understood. The well-known spherical concretions of Kettle Point, at the southern end of Lake Huron, appear to throw some light on the problem of the *mise en place* of thoroughly exotic material, aggregated by this slowly acting molecular attraction. The purpose of the present paper is to illustrate the mode of occurrence and to indicate some facts leading toward the interpretation of these singular bodies.

Logan has given us a concise description of the conditions at Kettle Point in the *Geology of Canada*, published in 1863.[1] Reference is also made to them by Rominger;[2] but in neither case was actual illustration employed nor description given of perhaps the most remarkable characteristic of the concretions.

About one half mile eastward of Kettle Point the highway from the town of Thedford decends sharply on a remarkably well preserved sea cliff of the formerly expanded Lake Huron, to the level of a gently sloping bench, cut in part in the drift, in part in the shales which underlie all this portion of Lambton county. At the Point itself the shales are seen to be wasting very rapidly on the face of a modern cliff from six to fourteen feet high and a few hundreds of yards in length. This condition is highly favorable to the exposure of the concretions, and one could hardly ask for more ideal sections for the study of structural details in the bed rock.

According to Logan these beds represent the equivalent of the Genesee Shale in New York state, which bears concretions of the same nature as those under consideration.[3] Rominger

[1] Pp. 387, 388.

[2] Rep. Geol. Sur. Michigan, Vol. III, 1873–1876, p. 67.

[3] Cf. Hall, Geology, Pt. IV, in the Nat. Hist. of New York, pp. 220 and 230.

put them in his "Black Shale" division of Michigan,[1] which C. E. Wright has called the "St. Clair Group."[2] The wide extent of these shales is further emphasized by their correlation with the important zone of the "Huron Shale" in Ohio.[3]

At the Ontario locality the rock is argillaceous throughout, of a dark brownish-gray to black color, which is partly due to

FIG. 1. General view of the shale at Kettle Point, showing jointing. Several concretions appear above the surface of the water.

the strong impregnation of bituminous matter, so abundant as to make the rock inflammable. Fossils are not rare; indeed, there is a very striking exhibition of large specimens of *Calamites inornatus*, and of other plants, lying prostrate in the shale. In addition to the calcareous concretions there is a great abundance of concretions of iron pyrites, which are, however, always small, generally lenticular, with the greatest diameter under three

[1] Op. cit., p. 67.

[2] Rep. Geol. Sur. Michigan, Vol. V, 1881–1893, Pt. II, p. 21 (ed. by Lane).

[3] NEWBERRY, Geology of Ohio, Vol. I, 1873, p. 154.

inches. The decomposition of the pyrites has led to the efflorescence of the usual sulphates of iron and alumina and of the hydrous oxalate of iron, humboldtite.

The shale is nearly horizontal, well laminated and very fissile, the flakes of the rock being readily split out and piled up on edge by the waves, which thus build a curious belt of jagged and

FIG. 2. Concretion and deformation of the shale.

shattered fragments on the bed rock. The only other notable structure in the interconcretionary spaces is the universal occurrence of two extremely perfect systems of vertical joints at right angles to each other (Fig. 1). These joints affect the shale only, and do not pass through the concretions anywhere, so far as I have had opportunity of observing the latter.

The most striking structure in the shales is, however, the local departure from the normal horizontal position of the parts of the beds in the immediate vicinity of the concretions. In every one of the dozen well-exposed concretions still in place the strata are plainly arched over the upper hemisphere and bend

under the lower, and show clearly the effect of deformation along the radii of the equator. In fact, the impression is at once given the observer that centrifugal force of nearly equal amount has been exerted along all radii of each sphere (Figs. 2, 3, and 5). A similar disturbance of the usual, nearly horizontal, attitude of the beds of this formation has been noted by New-

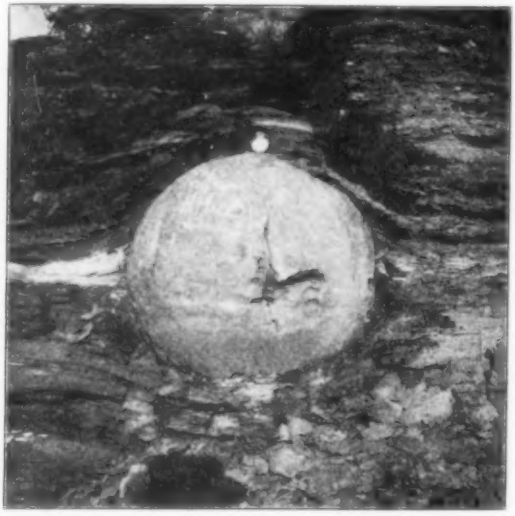


FIG. 3. Deformation of the shale about a medium-sized concretion.

berry at Worthington, Franklin county, Ohio,[1] and by Rominger in the "Black Shale" of Michigan.[2]

The concretions themselves are composed essentially of crystallized carbonate of lime, the crystals arranged radially and always in direct contact with one another. There is practically no argillaceous material in them, and in no observed case does the stratification of the country-rock run through the concretion. The shape is usually that of the almost perfect sphere (Fig. 4), though often this form is somewhat lost by the slight flattening

[1] Geology of Ohio, Vol. I, 1873, p. 155.

[2] Op. cit., p. 66.

of the concretion along the diameter perpendicular to the plane of stratification of the shale. True spheres and spheroids exhaust the list of observed forms. The average diameter is nearly two feet; the largest specimen now well exposed on the shore, a spheroid, has a polar diameter of a little more than three feet, an equatorial diameter of about three feet six inches

FIG. 4. General view of partially exposed concretions.

(Fig. 5); the smallest specimen may measure about one foot in diameter.

Large numbers of the concretions are being washed out of the much less resistant shales by the waves; their freeing from the matrix may be seen in all its stages (Fig. 4). But the number now remaining on the shore does not represent the total that could be counted were it not for the deplorable habit of the numerous visitors to the Point, who not only carry away the heavy specimens bodily, but break up others with the hope, destined to disappointment, of finding something at the core more

interesting than the interior of the already shattered "kettles." It is said that the concretions may be seen on the bottom in the very shallow water of the lake five or six miles from Kettle Point, and that specimens may be readily fished from the bottom as much as two miles from the shore, where they have been leached out by the erosive action of the larger waves.

FIG. 5. Large concretion in place; the shale in its immediate vicinity exhibits slaty cleavage developed tangentially to the concretion.

Composing as they do such a comparatively large proportion of the rock, and occurring in similar profusion in the Upper Devonian of Michigan and Ohio, it is hardly just to say, in the words of Dana, that radial spherical concretions are "of inferior geological importance.[1]

A chemical analysis of one of the darker tinted brown concretions was made, and yielded the following percentage composition:

[1] Manual of Geology, 4th ed., p. 97.

$CaCO_3$	88.42%
$MgCO_3$	2.99
Fe_2O_3	0.71
Residue insoluble in HCl (SiO_2)	4.25
Hydrocarbons (and H_2O)	3.23
	99.60

FIG. 6. Looking down on the concretion of Fig. 5; fractured surface shows concentric structure, the radial arrangement of the crystals not conspicuous in the photograph.

The powder from which this analysis was made was previously dried at ordinary temperatures in a desiccator; any residual water was driven off at the low heat used to expel the hydrocarbons. The latter cannot then be said to have been exactly determined, but they probably do not total less than 3 per cent. The shales round about were found by Hunt to contain 12.4 per cent. of volatile matter, presumably hydrocarbons.[1] The appearance of the magnesian carbonate is to be correlated with the

[1] Chemical and Geological Essays, p. 179.

observation by Garwood that some of this substance must be present if a limestone concretion is to grow large, although his analyses show that more than 30 per cent. of that carbonate seems to prevent the concretionary process.[1]

In all cases the structure is typically radial throughout the concretion, except at the rather indefinite small core of massive crystallized lime carbonate, which can usually be seen at the center. I have found no organic center of concretion, and no center other than calcite in any specimen. The free ends of the radiating crystals present the characteristic cleavage-planes of calcite, and the curved surface of the sphere is otherwise indented only by the faint depressions where the latter was in contact with the layers of shale (Fig. 5). Lastly, there is often to be seen, in addition to the radial structure, a concentric banding in the split-open sphere, a layering that seems to be original and connected with varying conditions of growth (Fig. 6).

The most important problem in connection with these concretions doubtless adheres to the question as to how the strata came to be deformed on all sides of each spheroid. That very considerable mechanical energy has been expended in the process is evident, not only in the development of a dome over the upper hemisphere and of a cup holding the lower hemisphere, but also in that of a sort of slaty cleavage, which can sometimes be discerned in the shale adjacent to the equatorial zone (Fig. 5). What is the source of the energy?

One of the first explanations that suggested themselves to me consisted in referring the deformation of the beds to differential movements in the strata as these adjusted themselves to the loss of water, and to the ensuing consolidation of the original muds to shale. The concretion itself would not lose bulk in such a case, and the layers overlying would be supported at the upper pole of the spheroid, while there would be less and less of such support for the same strata along lines radiating from the pole in the horizontal plane, until a maximum of instability would be reached outside of the equatorial circle. Here there would

[1] Geol. Mag., 1891, p. 439.

be a maximum of collapse which means, in the end, a doming above the upper hemisphere. I have found that the same explanation had been brought forward by both Newberry[1] and by Rominger.[2] But it leaves out of account the structural cup, which holds the lower hemisphere, and which is just as well developed as the dome overhead (Fig. 3). Moreover, the existence of the concretion before the act of consolidation is not considered; yet we must believe that a theory of the deformation should be controlled by the recognition of the fact that many cubic feet of the shale must be displaced to permit of the growth of the larger concretions.[3] We know of no reactions by which replacement of argillaceous material by slow molecular interchange with carbonate of lime may take place, nor can we conceive of such large spherical and spheroidal cavities as those necessary for the segregation of the calcite as having antedated the segregation. The last supposition is particularly invalid, for, in any case, it would leave the radial structure unexplained.

The same objection may be made to the hypothesis that energy sufficient for the deformation of the strata might be forthcoming in the process of forming a pseudomorph of calcite after some other carbonate of greater density. Siderite does, indeed, occur in radially concretionary form in the Black Shale of Michigan.[4] But, while there might be an important increase of volume with the application of expansive energy analogous to that ensuing on the change from anhydrite to gypsum, we have still to account for the original displacement of the shale to make way for the siderite or other earlier carbonate itself. It may also be stated that the disturbance of the shale is visibly greater than is possible on a mere change of volume in the pseudomorphosing reaction.

There thus seems to be no escape from the conclusion that the crystallization of each concretion and the opening of the

[1] Op. cit., p. 155. [2] Op. cit., p. 66.

[3] NEWBERRY's largest concretion of the sort here described, and occurring under similar conditions, measures 10 feet in diameter, giving a volume of more than 500 cubic feet. Geology of Ohio, 1873, p. 155.

[4] Geol. Surv., Mich., Vol. III, 1873–1876, p. 67.

space in which it lies were contemporaneous processes ; the force used in deforming the beds must, in some way or other, be directly connected with the act of crystallization of the calcite.

The theory of this association that lies nearest to hand would explain it by deriving active mechanical energy from each crystal of calcite as it obtains new material at the outer extremity on the surface of the growing spheroid. This energy will, then, be that of a "live force," and will be directed centrifugally, forcing the shale to assume a position dependent on the relative rate of growth of the crystals in the bundle. If there be equal supply of carbonate in the surrounding matrix, the radiating crystals will grow at equal rates; the aggregate will be spherical, and the layers of shale will be forced to assume a corresponding position. A rate of supply more rapid along the plane of stratification than in a direction transverse to that plane would give a spheroid with a minimum diameter similarly transverse to the bedding, and a corresponding distortion of the shale mantle. In brief, this hypothesis calls for the production of a compressive force exerted on the surrounding medium by a growing crystal.

Bischof has said that "what we know of causes in the growth of crystals, we have learned in the chemical laboratory. This is our sole guide to a conception of crystallization in the mineral kingdom."[1] It must be confessed that the advocates of the theory of live force exerted by natural crystals have been few, and that almost all derive their whole argument from observations in the geological field, and not from those in the chemical laboratory. Unfortunately, too, many of the examples chosen by them cannot be taken as sure evidence of the exertion of such force by a crystal of a primary mineral, *i. e.*, one that has gathered its molecules, one by one, from a mother liquor, and that by virtue of the attraction of like molecule to like. And this is the case with our calcite molecule. With but few exceptions the argument for live force has been taken from the study

[1] Lehrbuch der chem. phys. Geologie, 2d ed., Band I, p. 140.

of minerals like wavellite, natrolite, and other zeolites, gypsum, serpentine, talc, and other hydrous secondary minerals; possibly pseudomorphs in every case, and if so, of less density, and occupying greater volume than the parent mineral. Such swelling substance can exert active centrifugal force. But we have already noted the fact that this cause of crowding in rock-masses cannot aid us greatly in explaining the Kettle Point concretions.

Basing his statement on such doubtful examples as those just mentioned, Bischof says: "Crystallization is a force which may be compared with that of the expansive force of heat."[2] On the other hand, he quotes Kopp, who opposed Duvernoy in his theory of a mechanical energy of crystallization by showing that a crystal of alum growing in a vessel never does so by accretion on the face upon which the crystal rests at the bottom of the vessel. Kopp thus concluded that the mechanical energy of crystallization must be very slight, if existent at all, in this case, of a crystal of exceptional rapidity of growth that cannot overcome its own trifling weight when immersed in the mother-liquor.[1]

At the same time, certain observers have noted instances where live force seems to have been exerted during growth by crystals or crystalline aggregates, which may not, or, indeed, certainly have not, been pseudomorphous derivatives from pre-existing minerals. De La Bèche, speaking of crystalline concretions of selenite and of iron pyrites, stated his belief that, in these cases, chemical affinity was strong enough "to overcome the attraction of cohesion" in the matrix.[2] Dana's example of rifting of quartzite by the growth of a limonitic deposit, and the wedging asunder of parts of a tourmaline crystal by the crystallization of quartz in which the tourmaline lies embedded, are too well known to need more than mention.[3] Similarly, Worthen's disjointed crinoids, the plates of which were gradually separated by the deposition of quartz between them, are cited by Dana as

[1] BISCHOF, Lehrbuch, Band I, p. 134.

[2] Researches in Theoretical Geology, 1834, p. 91.

[3] Manual of Geology, 4th ed., p. 138.

proving displacement by the force of crystallization. More recently, Professor Shaler has appealed to the hypothesis of tensional force to explain the opening of certain vein-fissures, the latter not being explicable by the usually accepted idea of open fissures.[1]

In certain of these cases, it may be agreed that the mechanical force expended seems to have been applied *pari passu* with the process of crystallization; so far as I have been able to find direct statement of the mode of application, each writer signifies his belief that the crystal itself did the work of rifting or of crowding together. We have seen that what little experimentation has already been carried out so far, leaves this interpretation decidedly weakened. The question arises as to whether the energy is set free in the act of crystallization in ways other than in the form of a push exerted by the growing crystal. An answer has suggested itself to me, and I shall briefly outline it, without, I trust, seeming to imply that the idea is anything more than a somewhat highly specialized working hypothesis.

In the Kettle Point shales, saturation of the underground waters by both free and combined carbon dioxide is not hard to imagine. An abundant supply of the gas could be found in the decomposition of the carbonaceous matter in the shales;[2] the monocarbonate of lime is supplied in all necessary quantity from the calcareous bands in the shale and from the underlying Devonian limestones.

Suppose now that a small fragment of carbonate of lime, organic or other, is enclosed in a rock, with a capillary film between mineral and rock. This fragment will act as the immediate stimulus to the decomposition of any sufficiently saturated

[1] Bull. Geol. Soc. Amer., 1899, Vol. X, p. 259.

[2] The analysis of the gas given off from the "east crater" among the Mississippi mud-lumps of 1871 gave the following result: CO_2 9.41 per cent., marsh gas 86.20 per cent., N 4.39 per cent. HILGARD, Amer. Jour. Science, 1871, (1) p. 426. While the percentage of CO_2 is high, we may still regard this analysis as representative of the normal gases given off in the decomposition of vegetable matter buried in mud.

bicarbonated water that may be in contact with it.[1] Monocarbonate is precipitated about the fragment and a double biproduct is formed of water less strongly charged with the bicarbonate than before, and of carbon dioxide, which may be kept in solution in the water. The volume of new monocarbonate, together with that of the biproducts, is greater than that of the original bicarbonate;[2] expansion is necessary. The result would be the development of pressure directed centrifugally with respect to the fragment. This pressure will be the sum of all those minor pressures produced by the single decompositions of bicarbonated water entering by each of a million passages to the point where the solid carbonate is reached. The integrated force may have great efficiency. It would tend to expel the water from the surrounding capillary passages. If the expulsion kept pace with the crystallization, the space between the mineral and the adjacent rock-substance would soon be completely closed and crystallization and growth of the concretion would cease.

But the experiments of Jamin[3] have proved that equilibrium may exist between two unequal pressures affecting the ends of a capillary tube, provided a column of liquid occupying the tube be interrupted by bubbles of air. The presence of the latter excites capillary attraction which is so strong as to take up

[1] It is a familiar fact that crystallization can often be brought about, when not produced by other means, by introducing a crystal of the substance, the crystallizing of which is desired. Further, the mass of substance dissolved in water and coming in contact with a mineral, is very small compared with that of the mineral; if there ensue a chemical reaction, it is the large mass of the mineral that regulates the laws of affinity. Thus, solid carbonate of barium decomposes dissolved bicarbonate of calcium, and solid calcium carbonate decomposes dissolved barium carbonate; à fortiori, solid calcium carbonate will decompose dissolved calcium carbonate, i. e., the bicarbonate. Cf. BISCHOF, Lehrbuch, Band I, p. 114.

[2] That expansion will result has unfortunately not yet been proved by experiment in the case of $CaCO_3$, but it is inferred from the law that expansion of volume follows on the separation of salts from their solutions in those instances where increased pressure aids solubility. Engel has determined that the solubility of carbonate of lime in carbonated water increases very rapidly with an increase of pressure, e. g., doubling with a rise of pressure from one to six atmospheres. Comptes Rendus, Vol. CI, p. 949.

[3] Comptes Rendus, Tome L, 1860, pp. 172 and 311.

several atmospheres of pressure applied at one end of the tube. The force so expended is represented in the compression of the air bubbles and in changing the form of the air menisci; surface tension is thus overcome. The movement of the bubbles progressively decreases in the direction of the greater pressure until one is reached which is not disturbed at all so long as the pressures remain constant. The bubbles act like so many buffers. Any capillary tube filled with water interrupted by any insoluble gas or liquid possessing a lower surface tension than water, will exhibit the same phenomenon. Let us return to our incipient concretion.

Round about the grain of carbonate, there is an infinite network of capillary passages largely occupied by water in the early history of the rock. Along with the water, are gaseous and liquid hydrocarbons that are slowly being evolved by the decomposition of organic matter. The distribution of the hydrocarbons will be such as to bring about capillary attraction, and therewith the possibility of differential pressures within the water-mass, though it be in equilibrium throughout. Thus at the capillary film separating lime fragment and argillaceous wall, we may have great outward pressure unaccompanied by the expulsion of water along the channels leading from the country rock to the fragment. The latter is girt about with a mesh of capillary passages enormously resistant to movement of the contained liquids, and permitting of greater hydrostatic pressure within than without. The form of the mesh itself may change however, without interfering with its function as a buffer. The centrifugal pressure will then be occupied in deforming the rock, and it may conceivably be aided by the expansive energy of the freed CO_2. Fresh supplies of bicarbonated water will slowly diffuse into the capillary space between concretion and rock and further the displacing process. The solid carbonate as it were, keeps pulling a trigger that sets off the reaction of decomposition, which does not occur at a distance from the fragment. The biproduct cannot escape as fast as formed and the country-rock must be crowded away. The deformation is then, analogous

to that produced by the freezing of water in a closed vessel, being caused by a change of volume, and not by the thrust of the crystals as such.

Much of this general scheme can be applied with certainty to the Kettle Point concretions. Bicarbonated water unquestionably was the source of the calcite substance; the decomposition was induced locally at the call of pre-existent carbonate, and the double biproduct described must have resulted. Since the joints in the shale are undoubtedly due to desiccation, it is but fair to suppose that the concretions antedate them. The presence of hydrocarbons during the concretionary growth is likewise reasonable. The resulting surface tension in this deeplying water would thus bring about capillary action which was especially powerful on account of the extremely small size of the channels through which water could migrate in the shale.

The shape of the growing concretions will depend primarily on the resistances offered to displacement by the shale, and, perhaps, secondarily, to the rate of supply of bicarbonate. From the homogeneous character of the shale, we are led to believe that both of these actions will be nearly equal in all directions throughout the rock, with, however, a slight advantage in power of resistance to be ascribed to the direction at right angles to the plane of stratification. The resulting form of the concretions would, in consequence, be that of a sphere or of a spheroid. The calcite crystals will assume radial positions according to a law of crystal growth that does not concern us here; they will grow outward into the shallow space offered by the outward thrust until the biproduct has slowly diffused through the argillaceous wall.

In conclusion, then, it may be stated that the concretions were formed in place within the shale, that they antedate the period of joint development and final consolidation of the surrounding rock, that the local deformation of the shale accompanied the process of crystallization, and that the energy of the deformation appears to have been derived from the change of volume induced by the breaking up of the bicarbonate into

monocarbonate and fluid biproduct. The introduction of capillarity to explain the existence of differential pressures in the rock-mass cannot be regarded as other than hypothetical. It is hoped that the suggestion may lead to fruitful experimentation; for it is doubtless to the experimental geologist and to the physical chemist that we must finally appeal in determining the source of mechanical energy in deep-seated chemical reactions. The hypothesis should, of course, also be tested by reference to the conditions at other localities where deformation in sedimentary rocks has been produced during the growth of concretions, whether composed of calcite or of other material.

REGINALD A. DALY.

ANTS AS GEOLOGIC AGENTS IN THE TROPICS

A FEW years ago in treating the subject of the decomposition of rocks in Brazil I spoke of ants as geologic agents worthy of consideration[1] My claims for these humble workers were apparently accepted under protest. With this protest I confess I have much sympathy, for if I had not seen with my own eyes so much of these ants and their remarkable deeds I never should have believed half the stories told of them.

Last summer while visiting Brazil again I made a few notes upon the ant-hills in the State of Minas Geraes, and took a photograph showing the kinds of hills so common in certain parts of that state. I went into the interior at one place by the Bahia and Minas railway, which, starting from the coast near Caravellas in the State of Bahia, runs to Theophilo Ottoni (formerly called Philadelphia) in the State of Minas, a distance of 376 kilometers. The first 160 kilometers of the road is over campos of hard baked Cretaceous clays with only patches of forest here and there. Beyond this the rocks are crystalline, mostly gabbros and gneisses, up nearly to the end of the line where the rocks are old metamorphic mica schists, itacolumites, etc., all deeply decomposed. Shortly after leaving the Cretaceous area my attention was attracted by the big ant-hills in the forests. These mounds are from three to fourteen feet high and from ten to thirty feet across at the base. The new ones are steeply conical and the old ones are rounded or flattened down by the weather. In many places these mounds are so close together that their bases touch each other.

An ant-hill at Urucú station, Bahia and Minas railway.

About Urucú station (k. 226) the ant-hills are so thick that the country looks like a field of gigantic potato hills.

[1] Decomposition of rocks in Brazil, by J. C. BRANNER: Bul. Geol. Soc. Amer., 1896, VII, 295–300.

In the vicinity of the city of Theophilo Ottoni there are several old fields apparently abandoned to the ants. The accompanying plate is from a photograph taken on the slope of the hills west of the railway station at this city. The mounds here are all low and rounded as if they were old.

I regret that this picture does not give a better idea of the size and abundance of the ant-hills; unfortunately it was taken when the sun was almost directly overhead, and the view is up the slope and along the side of the hill. Before the photograph was made the man in foreground was sent behind the hill at the foot of which he sits, but though he was over six feet high I could only see the top of his hat. The black lumps shown are hard masses weathered from the large mounds.

Ant-hills in an old field on the Rio Mucury, State of Minas Geraes, Brazil.

In the city of Theophilo Ottoni the streets are cut down in many places through the rock decayed in places. In some of the fresh cuts I observed the holes made by ants penetrating the ground in one place to a depth of ten feet, in another to a depth of thirteen feet, below the surface of the ground; many others were seen at a depth of six, seven and eight feet below the surface.

It goes without saying that the ants do not bore into the hard undecayed rocks, but it seems reasonable to suppose that the opening up of the ground by their long and ramifying underground passages hastens decay, and that the working over of the soil must contribute more or less to the same end.

The impression one gets from the work of the ants along the line of the Bahia and Minas railway — and for that matter in any other part of the tropics — is that they are vastly more important as geologic agents than the earthworms of temperate regions.

Since the publication of my paper upon the decomposition of rocks in Brazil, in which several writers are quoted upon the work

of ants in that country, I have found a few interesting notes upon the subject some of which I quote here.

Speaking of the ants in the River Plate country Sir Woodbine Parish refers to "Corrientes and Paraguay, where whole plains are covered with their dome-like and conical edifices, rising five and six feet in height."[1]

Ant-hills on the hills west of the city of Theophilo Ottoni, State of Minas Geraes, Brazil.

The Robertsons mention ants' nests among the palms near Assuncion, Paraguay, as "thousands of conic masses of earth, to the height of eight and ten feet, and having a base of nearly five in diameter."[2]

Referring to the injury done to crops by the saúba ants the president of the Imperial Instituto Fluminense de Agricultura says: "Among the obstacles with which planters have to contend . . . . there stands perhaps in the front ranks the destructive force represented by the saúba."[3] JOHN C. BRANNER.

[1] Buenos Ayres and the provinces of the Rio de la Plata, by SIR WOODBINE PARISH: 2d ed., p. 252. London, 1852.

[2] Letters on Paraguay, by J. P. and W. P. ROBERTSON, Vol. I, 270–274. London, 1838.

[3] Henrique de Paulo Mascarenhas in the Revista Agricola do Imperial Instituto, December 1883, XVI, 215.

VARIATIONS OF GLACIERS. V.[1]

THE following is a summary of the fourth annual report of the International Committee on Glaciers:[2]

RECORD OF GLACIERS FOR 1898

Swiss Alps.—Of the seventy glaciers which were measured in 1898, twelve are advancing, fifty-five retreating and the others doubtful.[3]

Eastern Alps.—The variations reported last year on the Gliederferner and Vernagtferner are confirmed by further measures. The swelling of these glaciers continues to advance down the valley and to carry with it an increased velocity of motion. When it reaches the end of the glacier there will be an advance of the ice. The majority of the glaciers are retreating, though a few of them are advancing. On the whole the tendency to retreat seems to be increasing.[4]

Italian Alps.—The glaciers of Mount Disgrazia, and those of the south side of the Bernina group are all retreating at the rate of several meters a year.[5]

Scandinavian Alps.—The glaciers of Sweden so far as observed show insignificant changes. They are probably stationary. The velocity of the Stuorajekna near its end was found to be about twice as rapid in summer as the annual average.[6]

Polar Regions.—In 1898, the large glacier between Mt. Hedgehog and South Cape, Spitzbergen, was found to project several kilometers into the sea. This glacier is not shown on former maps, and it is therefore possible that it has recently made a great advance.[7]

[1] The first four articles of this series appeared in this JOURNAL, Vol. III, pp. 278–288; Vol. V, pp. 378–383; Vol. VI, pp. 473–476, and Vol. VII, pp. 217–225.

[2] Archives des Sciences Phys. et Nat., Vol. VIII, pp. 85–115.

[3] Report of Professor Forel.

[4] Report of Professor Finsterwalder.

[5] Report of Professor Marinelli.

[6] Report of Dr. Svenonius.

[7] Report of Dr. Nathorst.

Greenland.— Steenstrup and Drygalski have both concluded from their observations, that the great cold of winter greatly reduces the velocity of motion of the smaller glaciers, but that the large glaciers, nourished by the inland ice, are very little affected by the seasons. Drygalski has found a velocity of twenty meters per day in the great Karajak glacier. The Asakak glacier on the Nugsuak Peninsula has been observed at intervals for fifty years. It retreated nearly a kilometer between 1849 and 1879, and has since then advanced even more. The Sermiarsut glacier no longer reaches tide water as it formerly did, but the other small glaciers of this region show no marked changes. The Blase Dale glaciers on the island of Disco, have continued to retreat since the visit of Professor Chamberlin in 1894.[1]

Canada.— The Upper Bow glacier is slowly advancing, but it has not yet reached the extent indicated by former moraines. Freshfield glacier was advancing in 1897, plowing up the débris in front. Stutfield glacier has been covered with débris by great avalanches, and the melting has thus been retarded. As a result the ice is advancing down the valley and is now in the midst of the forest. It is at least a half mile beyond its former limits. The Illecellewaet glacier has retreated 100 to 150 meters since 1888, and probably 200 meters within the present century.

Himalaya.— The Tarsching glacier apparently retreated between 1850 and 1870, at which latter date it was advancing. It seems to be advancing at present and may block up the valley above it, and cause inundations as it has done before.

Africa.— Dr. Hans Meyer visited the cone of Kibo, the highest point of Kilimanjaro, in 1898 and described the extent of its glaciers. The summit is about 6000 meters high, and the ice streams down on all sides. On the northern and eastern sides the winds are dry, and the glaciers only descend a few hundred meters; whereas on the southern and southwestern sides, the winds are moist and one glacier descends as much as 2000 meters from the summit. There has been a distinct retreat since Dr. Meyer's visit in 1889. Dr. Meyer has also discovered

[1] Report of Dr. Steenstrup.

traces of a glacial period on Kilimanjaro, which confirms similar observations of Gregory further north on Kenia.[1]

Caucasus.—The glaciers in the neighborhood of Mt. Elbruz are retreating at the rate of eight or ten meters a year, with the exception of the Adyl, which has advanced six or seven meters between 1897 and 1898.[2]

REPORT ON THE GLACIERS OF THE UNITED STATES FOR 1899[3]

Montana.—Sperry glacier, discovered a few years ago, is retreating—(*L. B. Sperry*).

Mt. Adams, Wash.—This volcanic peak, like the others of this region, has a number of glaciers streaming down its sides. The White Salmon and the Mazama, respectively, on the southwestern and southern slopes of the mountain, are broad and comparatively short masses of ice. Each divides into two tongues. The White Salmon is largely covered with débris, while the surface of the Mazama is clean to its ends, though it has a large lateral moraine. The causes of these differences do not appear.

On the eastern side of the mountain are the Klickitat and Rusk glaciers, both of which lie in deep canyons. They are two or three miles long, the latter being the shorter. The Klickitat is connected with the ice-cap of the mountain through three couloirs, and is also nourished by ice avalanches which fall down the great precipice which characterizes the eastern side of the mountain. The Rusk derives all its material from avalanches. Neither are free of moraines. The other slopes of the mountain are not cut into ravines and the glaciers on the northern side, probably four in number, are not very distinctly separated from each other; they are also thoroughly covered with débris, so that they could not be readily distinguished from a distance.

The Klickitat glacier was retreating in 1890 (*C. E. Rusk*), but no information is available regarding the variations of the others.[4]

[1] Report of Mr. Norman Collie. [2] Report of Mr. Mouchketow.

[3] A synopsis of his report will appear in the Fifth Annual Report of the International Committee. The report on the glaciers of the United States for 1898 was given in this JOURNAL, Vol. VII, pp. 221–225.

[4] The account of these glaciers is taken from descriptions by Professor W. D. Lyman and Mr. C. E. Rusk in the Mazama Magazine, Vol. I, and from a special communication from Mr. Rusk.

Mt. St. Helens.—A glacier on the north side of this mountain was advancing and destroying trees in 1895 (*C. E. Rusk*).

Mount Ranier.—The Nisqually glacier has retreated not less than 100 meters since 1894 (*E. T. Allen*).

Alaska.—Last summer, Mr. E. H. Harrington of New York, invited a number of scientific men to accompany him on a voyage along the Alaskan coast. The full results of the expedition are to be published by the Washington Academy of Sciences.

Twenty-two tide-water glaciers were examined and marks left near many of them by which future changes may be measured.

Photographs and observations made by several members of the expedition show that all the glaciers visited are now retreating except the Crillon glacier on the west side of Mt. Crillon. This glacier does not reach tide-water; it is advancing against the forest and destroying the trees.

Prince William Sound.—Mr. Gannett mapped the glaciers and found that they are all retreating. The Harvard and Yale glaciers have retreated nine miles in a century.[1]

The Columbia glacier is now retreating, but the disturbed ground in front of it shows that it has recently advanced. The young trees growing on this disturbed surface place the date of the advance eight or nine years ago. The Muir glacier made an advance about the same time (*G. K. Gilbert*).

Glacier Bay.—All the glaciers seem to be retreating. In 1879, the three glaciers at the head of the bay were united and three or four miles in advance of their present positions. The Charpentier and Hugh Miller also formed one glacier and extended two or three miles further than they now do. Rendu and Carroll glaciers have suffered decided recessions since 1896 (*John Muir*).

A comparison of photographs taken by Mr. Gilbert in 1899, with others taken by the author in 1892, shows that in that

[1] The Harriman Alaska Expedition, by Henry Gannett, Nat. Geog. Mag., 1899, Vol. X, pp. 507–512; and Bull. Amer. Geograph. Soc., 1899, Vol. XXXI, pp. 345–355.

interval, the Grand Pacific glacier has retreated 500 to 600 yards; and the Hugh Miller 300 to 400 yards; the tide-water end of the Charpentier has receded nearly a mile and the Alpine end is now a mass of disconnected dead ice.

The records of Muir glacier are increasing. We know approximately its extent in 1880 from Professor Muir; and in 1886 from photographs by Professor Wright; and accurately in 1890 and 1892 from surveys by the author; pretty well in 1894 from photographs by La Roche of Seattle, and accurately again in 1899 from surveys by Mr. Gannett. With the exception of a slight advance between 1890 and 1892 the glacier has been pretty steadily receding. At present its extreme point in the middle of the inlet is not much behind its position eight or ten years ago, but the sides have receded fully half a mile. Morse glacier, a tributary on the west, became entirely separated from Muir glacier between 1892 and 1894 and continues to get shorter. Dirt glacier will probably also be an independent glacier before long.

Mr. Otto J. Klotz, of the Canadian Topographical Survey, concludes from a comparison of Vancouver's description of Taylor Bay with its present extent, that the Brady glacier in 1794 was at least five miles shorter than in 1893, when the Canadian survey was made, and that at the earlier date the glacier ended in tide-water. At present its end rests on gravels and does not quite reach the sea. These gravels must then have been laid down in the interval. He also concludes from Vancouver's descriptions and that of Sir George Simpson regarding Stephens' passage in 1841, that all the glaciers south of Fairweather Range have been steadily retreating in the last century. This, however, does not preclude temporary advances of individual glaciers, such as the Patterson, which, according to the *Pacific Coast Pilot* of 1891, was advancing and destroying trees at that time. The Le Conte glacier is at the head of a fiord about six miles long, and has retreated about half a mile between 1887, when the United States Coast and Geodetic Survey chart was made, and 1893, the time of the Canadian survey. A

description of this region by Vancouver does not give any reference to this fiord. It is therefore probable that it was entirely filled with ice a hundred years ago, which would indicate a retreat of Le Conte glacier of six miles in a century.[1]

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March 22, 1900.

[1] Notes on Glaciers of Southeastern Alaska and Adjoining Territory, by OTTO J. KLOTZ: Geog. Jour., 1899, Vol. XIV, pp. 523–534.

STUDIES FOR STUDENTS

THE PROPERTIES OF BUILDING STONES AND METHODS OF DETERMINING THEIR VALUE[1]

I. NECESSARY CONSIDERATIONS IN THE SELECTION OF STONE

QUARRY observations, building inspection, and laboratory examination of building stone are conducted to satisfy the individual and the public that the stone under consideration possesses a color which will remain permanent and inherent qualities which give it a capacity to effectually withstand the atmospheric and other conditions to which it will be subject when in use.

It is my purpose in this number to discuss: (1) Color; (2) the inherent qualities of stone which limit its capacity to withstand atmospheric and other conditions; and (3) the atmospheric and other conditions to which building stone may be subject. In a following number quarry observations, building inspection, and the laboratory examination of building stone will be considered.

[1] This subject has been discussed very freely by geologists, architects, and engineers for twenty or twenty-five years. Many of the ideas expressed in this and the following number are a repetition of the conclusions reached by men who have previously entered this field of discussion. However, it would be a very uncertain task to endeavor to give any one credit for first enunciating the principles herein stated.

The following is a list of the more important American publications which treat, more or less fully, the subject considered in these studies, and to which the reader is referred: The Experimental Tests of Building Stones, by ROBERT G. HATFIELD, Trans. Am. Soc. of Civil Engineers, Vol. XLVIII, pp. 145–151, 1872; Report on the Building Stones of the United States, Appendix of the Annual Report of the Chief of Engineers, U. S. A., 1875; Notes on Building Stones, by HIRAM A. CUTTING, Vermont, 1880; Building Stones of Colorado, by REGIS CHAUVENET, Report of the Colorado School of Mines, pp. 1–16, 1884; The Building Stones of Minnesota, by N. H. WINCHELL, Report of the Geological and Natural History Survey of Minnesota, Vol. I, pp. 142–203, 1884; Special Report on Petroleum, Coke, and Building Stone, The Tenth Census of the United States, 1884; Report on Building Stones, by JAMES HALL, Thirty-ninth Annual Report of the New York State Museum of Natural History,

Color.—The predominant colors of stone are white, gray, brown, red, yellow, buff, blue, black, and green.[1] Ordinarily the color of a rock is not simple but composite, being a resultant of the different colors of the constituent minerals.

The sedimentary rocks on account of the simplicity of their mineral composition approach more nearly to what is known as a simple color than do the igneous. The shades of brown, buff, yellow, red, gray, or blue imparted by a sedimentary rock are mainly attributable to the presence of the oxide, carbonate, or sulphide of iron, bitumen, and carbonaceous matter in the form of graphite. The white and gray colors of marble, limestone, and dolomite may be attributed to the calcite or dolomite of which the rock may be composed.

pp. 186–224, 1886; The Collection of Building and Ornamental Stones in the United States National Museum, by GEORGE P. MERRILL, Smithsonian Report, Part II, pp. 277–520 1886; Igneous Rocks, by J. F. WILLIAMS, Annual Report of the Arkansas Geological Survey, Vol. II, 1890; Building Stone in the State of New York, by JOHN C. SMOCK, Bulletin of the New York Museum of Natural History, Vol. III, No. 10, 1890; Marbles and Other Limestones, by T. C. HOPKINS, Report of the Arkansas Geological Survey, Vol. IV, 1890; Stones for Building and Decoration, by GEORGE P. MERRILL, John Wiley and Sons, 1891 and 1898; The Onyx Marbles, by GEORGE P. MERRILL, Report of the United States National Museum, pp. 539–585, 1893; Marbles of Georgia, by S. W. MCCALLIE, Bulletin No. 1 of the Geological Survey of Georgia, 1894; Notes upon Testing Building Stones, by T. LYNNWOOD GARRISON, Trans. Am. Soc. of Civil Engineers, Vol. XXXII, pp. 87–98, 1894; The Relative Effect of Frost and the Sulphate of Soda Efflorescence Tests on Building Stones, by LEA MCI. LUQUER, Trans. Am. Soc. of Civil Engineers, Vol. XXXIII, pp. 235–256, 1895; Report on Tests of Metals, etc., at Watertown Arsenal; Reports of the United States War Department, pp. 322, 323, 1895; also 1890 and 1894; The Building Materials of Pennsylvania; I, Brownstones, by T. C. HOPKINS, Appendix to the Annual Report of Pennsylvania State College for 1896; The Bedford Oolitic Limestones of Indiana, by T. C. HOPKINS and C. E. SIEBENTHAL, Twenty-first Annual Report of the Department of Geology and Natural Resources of Indiana, pp. 290–427, 1896; Properties and Tests of Building Stones, by H. F. BAIN, Eighth Annual Report of the Iowa Geological Survey, 1898; The Building and Decorative Stones of Maryland, by GEORGE P. MERRILL and EDWARD B. MATHEWS, Report of the Maryland Geological Survey, Vol. II, pp. 47–237, 1898; The Building and Ornamental Stones of Wisconsin, by E. R. BUCKLEY, Wisconsin Geological and Natural History Survey, Bulletin No. IV, 1898. Reference should also be made to the Engineering, Mining, Architectural, Building, Stone, and similar technical journals in which this subject is discussed in current articles.

[1] Speaking from the purely scientific standpoint all of these are not colors, although they are referred to as such in this paper.

When iron occurs in sedimentary rocks, more especially sandstone, it often serves as a cement by which the original particles are bound together. However, it may also occur as an original constituent in the shape of finely disseminated particles. Carbonaceous matter in the form of graphite, or bitumen in the shape of petroleum occurs mainly in limestone and marble, often contributing to these rocks the blue or grayish-blue colors so commonly observed.

Among sedimentary rocks the color varies widely, not only in the same quarry, but often in the same bed. Certain beds in a quarry may have a delightfully cheerful, uniform color, while those immediately above or below may be dull and somber. In many places the coloring matter is distributed through the beds in regular bands, but occasionally it is very curiously disseminated, forming irregular, fantastic figures. White sandstone is often colored with large and small brown spots, while brown sandstone is sometimes similarly variegated with white spots. All stone which is distinctly mottled or irregularly colored is known as "variegated stone."

The color of an igneous rock is usually composite, as a result of the blending of the distinct colors of the mineral particles. The color, however, does not depend entirely upon the colors of the individual minerals, but in part upon the size and distribution of the constituent particles. In some instances the individual grains are sufficiently large to retain their own color, and the stone is spoken of as being mottled.

With respect to color, granites are ordinarily classified as red and gray. Whether a granite belongs to the first or second class will depend mainly upon the red or white color of the feldspar. Many granites contain both red and white feldspar, but as long as the red variety is sufficiently abundant to impart a reddish tone to the rock, it is called red granite. The most brilliant red granites have a preponderance of medium-sized, deep red feldspar individuals. As the feldspar individuals become finer grained and less deeply colored and biotite, amphibole, or pyroxene becomes more abundant, the color is subdued producing dull red effects.

The gray granites are dark or light colored, depending upon the size of the individual grains and the amount and kind of the ferro-magnesian minerals present. The light-colored granites have a preponderance of white feldspar and quartz, with muscovite as the main ferro-magnesian mineral. The dark gray granites contain less feldspar and quartz, and a greater abundance of biotite, hornblende, pyroxene.

Other igneous rocks such as "labradorite granite" with its blue iridescent color, and rhyolite with its almost black color, are commonly met with. The iridescent color of the former is imparted by the abundant porphyritic individuals of labradorite, of which the rock is largely composed. The black color of the latter is due largely to its semi-crystalline groundmass, which often abounds in fine crystals of hornblende. Serpentine is an abundant constituent of some rocks, and as such imparts to them a green color. The dull greenish-gray color so conspicuous among the basic rocks such as gabbro, diorite, and diabase, is imparted mainly by the minerals of the hornblende, pyroxene, amphibole, chlorite, and epidote groups.

The color of a rock when freshly quarried may be almost perfectly white but a few years, or perhaps months, of exposure to the weather may change the color to a buff, or streak it with irregular patches of brown. Such color changes result chiefly from the presence of easily decomposed minerals within the stone itself. The yellow color of many limestones is due to the presence of finely disseminated iron, as the carbonate or sulphide, which has altered to the oxide. If a stone contains either of these the color will change as a natural consequence of exposure to the atmosphere. The oxides of iron are more stable compounds than the sulphide or carbonate, and very seldom cause a change in color.

A change in the color of the stone in a wall may be due to impurities in the mortar, cement, brick, or water used in the construction and not to the presence of easily decomposed minerals in the stone. The committee appointed to investigate the cause of the brown stains on the walls of the State Historical Library

Building at Madison, Wis., reported that the Bedford limestone, out of which the building is constructed, was practically free from ferrous iron, and that the cause of the iron staining was attributable mainly to the cement used in the back wall. This is probably a frequent cause of discoloration, on account of which good stone has been condemned. A common method of preventing the ferrous iron in the brick or mortar of the back wall from coming to the surface, is to use a coat of asphalt between this and the stone facing. A better precaution would be to select lime, cement, and brick from which ferrous lime is known to be absent.

A change of color through the decomposition of iron sulphide and carbonate is manifest mainly among the light colored rocks. The blue or gray limestones and dolomites are often discolored by spots or irregular efflorescent patches of calcium or magnesium sulphate, which appear as a white precipitate on the surface. Their presence at this place is attributed to interstitial water, which comes to the surface bearing soluble salts of magnesium and calcium, mainly the former. Dark colored rocks such as brown sandstone do not discolor, but occasionally they take on a lighter tint after long exposure to the weather. This comes about through the loss of iron oxide which is washed off from the surface by the rains. Decoloration, however, takes place so slowly that it is not an important consideration.

Very often, through long exposure in the quarry a rock, such as the blue limestone of the Trenton formation, is partly or entirely altered in color to a buff. Near the surface, beds may be found that have been completely altered, while deeper in the quarry one passes from those that are partly altered to those that are unchanged. The alteration commences along the joints and gradually passes toward the center of the blocks.

The manner in which a stone is dressed sometimes affects the permanency of its color. A rough dressed stone furnishes a multitude of places in which dust and dirt may lodge, while one which is smooth dressed is free from such places. For this reason there is less danger of the original color being obscured in a smooth

than in a rough dressed stone. On the other hand a smooth dressed stone emphasizes blemishes in color which may be obscured by rough dressing. These color blemishes may be more unsightly than the "tan" of smut and dust, in which case it would be preferable to rough dress the stone.

Fashion, dominated by color, influences the exploitation and the market value of different stones. Until a few years ago brownstone was preferred, both for business blocks and residences, but people became weary of gazing at long rows of somber colored buildings and the fashion changed to light colored stone. At the present time immense quantities of light colored stone are being used, but the fashion will change again in a few years and the pendulum will swing back to brownstone. A judicious use of both would serve to relieve the monotony of long rows of brownstone buildings and of the dazzling glare of white limestone and marble. It is to be hoped that the time will come when the use of neither light nor dark stone will be supreme.

In the large cities, other things being equal, the permanence of color ought to be a factor worthy of consideration in the erection of residences and tenement houses. However, in the construction of business blocks it scarcely warrants serious attention. A white limestone or marble structure erected in the midst of a business portion of a large city soon loses its original color, becoming gray and dingy from the omnipresent smoke and dirt. If the limestone is bituminous and contains a small amount of oil, all the dust and smoke which chances to fall upon it will be retained. The walls of most of the buildings in the business section of our large cities eventually become so begrimed with smoke and dust that it is barely possible to tell whether the stone was originally dark or light colored. One needs to familiarize himself with the characteristic brown and gray shades of stone which have been steeped for years in a smoke and dust laden atmosphere, in order to be able to determine the original colors.

On the whole the dark colored stone shows much less than does the light the effects of smoke and dust. Nevertheless the

only consideration in the selection of stone to be used in the business portion of a large city should be strength and durability.

In the suburban and resident parts of a city and in rural districts, where smoke and dust are trifling matters, the original color will not suffer seriously from external causes alone. In these places beauty is one of the chief ends of architecture, and a judicious scattering of light and dark colored stone buildings adds very materially not only to the appearance of the street as a whole, but also to the beauty of the dwellings individually.

When used for interior decorations, a stone does not suffer materially from atmospheric agencies, and the color will ordinarily remain permanent. The selection of stone for these uses, then, becomes largely a question of taste. A color which harmonizes with the surroundings or matches the other work, is generally considered most appropriate. In the flooring or steps, the capacity which the stone has to withstand abrasion without becoming unduly slippery, and not color, should be the controlling factor.

For monumental purposes the taste of the purchaser is again the main, controlling factor in the color selected. The stones used for monuments are mainly igneous and metamorphic (granite and marble), and as such contain few minerals which will result in discoloration. If pyrite or marcasite are constituents of the stone there will be danger of discoloration. However, the fact that most of the water which falls upon a granite monument is shed by its polished surface, lessens the danger of discoloration, by preventing decomposition.

In the more common uses to which stone is put, such as road making, sidewalks, retaining walls, cribs, breakwaters, bridge abutments, etc., the element of color seldom enters. In the case of retaining walls and sidewalks, which are partially ornamental in nature, color should receive appropriate consideration.

II. INHERENT QUALITIES OF STONE

The capacity which a stone has to withstand the forces tending to destroy it, is known as durability, and depends upon the

mineralogical composition, and the texture or state of aggregation of the mineral constituents. A consideration of the mineralogical composition implies reference to the characteristics of the different kinds of minerals and their relative abundance. By texture is meant the size, shape, manner of contact, and arrangement of the mineral particles. The strength, hardness, elasticity, structures, the effect of alternating heat and cold, and the effect of acids, depend upon both the mineralogical composition and the texture. The specific gravity as ordinarily computed depends upon the mineralogical composition alone; the porosity on the texture; and the weight per cubic foot on the specific gravity, and porosity.[1]

Mineralogical composition.—The most common minerals that enter into the composition of building stones are quartz, feldspar, mica, calcite, dolomite, kaolin, pyroxene, amphibole, and serpentine. These minerals have a respective hardness of 7, 6, 2–3, 3, 3.5–4, 1, 5–6, 5–6, 3–4. With the exception of quartz they all have one or more well-developed cleavages.

Quartz is perhaps the commonest of these minerals. It is the hardest, but probably neither the strongest nor most elastic.[2] Under ordinary conditions of temperature and pressure it is little, if at all, acted upon by the common acids. These conditions, combined with the fact that it possesses no ready cleavage, makes it one of the most durable and stable rock-forming minerals.

Feldspar is also a very common mineral, especially in the igneous rocks. It is softer than quartz, but probably stronger and more elastic. It cleaves readily in two directions. Under ordinary conditions of temperature and pressure it is little acted upon by the common acids. In the quarry, decomposition of

[1] It has been customary to consider the minerals of igneous rocks as primary, and secondary, while the secondary mineral matter in sedimentary rocks is known as cement. In this paper minerals are considered without reference to their origin, and therefore the terms secondary, primary, and cement, have been purposely omitted.

[2] Thus far I have been unable to obtain the crushing strength or coefficient of elasticity of the common minerals. I expect that these constants have been determined although my attempts to obtain them have been unsuccessful.

feldspar takes place very slowly, but owing to the fact that it often occurs in granite and other rock of great age, it is frequently in an advanced stage of alteration. The alteration products of feldspar are objectionable only in so far as they yield more readily to disintegration.

Mica is also a very common mineral, occurring most abundantly in the metamorphic rocks. The ready cleavage by which the mineral splits into thin plates, provides an easy passage for water, by which disintegration proceeds more rapidly than in the associated minerals. Mica is undesirable in proportion to the size of the individuals. If present in small isolated flakes, as it ordinarily occurs in sandstone, it is scarcely less durable than quartz and feldspar, but if the individuals are large or the flakes clustered together, disintegration will proceed more rapidly. Decomposition through chemical agencies goes on very slowly.

Calcite is almost as common as quartz, although far less permanent at the surface of the earth. It possesses three prominent cleavage directions, on account of which it disintegrates quite readily. The hardness, and probably the strength and elasticity, are all less than in quartz. It is quite easily soluble in carbonated waters and is readily acted upon by cold, dilute hydrochloric acid.

Dolomite differs from calcite mainly in its somewhat greater hardness, and the greater difficulty with which it dissolves in cold dilute hydrochloric acid. Its cleavage, hardness, strength, and elasticity are such that it disintegrates almost as readily as calcite, although it is taken into solution somewhat more slowly.

Kaolin is an important constituent of slate, being however, mainly of secondary origin. It is one of the softer minerals, has a perfect cleavage, and readily disintegrates. It is not acted upon chemically except under the most favorable conditions.

Pyroxene is one of the less important building-stone minerals. It cleaves perfectly in two directions, and breaks down slowly through mechanical abrasion. It gradually decomposes in the quarry when in the presence of water.

Amphibole has about the same strength and capacity to withstand abrasion and chemical influences as pyroxene.

Serpentine occurs in certain green colored rocks, such as verde antique, and is usually an alteration product of olivine.

Among the accessory mineral substances in building stones may be mentioned *pyrite, marcasite, hematite, magnetite, graphite, and bitumen.* Pyrite and marcasite in which the iron occurs partly in the ferrous state decompose quite readily in the presence of moisture, forming ferrous sulphate, which is brought to the surface by capillarity and deposited as iron oxide. Through the decomposition of pyrite, occurring in limestone or dolomite, magnesium and calcium sulphates are formed, which are taken into solution and redeposited at the surface as a white efflorescence.

Hematite and magnetite frequently impart a red, brown, yellow, or black color to the stone, but are not considered harmful.

Carbonaceous matter occurs in the form of graphite, and bituminous matter in the form of petroleum. The gray and black shades of limestone and marble are often due to the abundance of graphite. Petroleum occurs mainly in limestone, and is objectionable on account of the discoloration which is apt to result from the adherence of dust.

The occurrence of gaseous inclusions in the minerals, especially in quartz, is said to be a cause for the shattering of a rock when subjected to high temperatures. To what extent these inclusions influence the results of high temperatures on rock is unknown. The probability is that any temperature which would make these gases active agents of destruction would destroy the rock through unequal expansion of the mineral particles.

The hardness, strength, elasticity, and resistance of the stone to chemical action and alternating temperatures is influenced by the relative abundance of the mineral particles. If the percentage of quartz is large, the hardness is proportionately great—provided the size, shape, arrangement, etc., are constant. The strength and elasticity also increase as the minerals in which these properties are best developed are increased. However, it must be understood that a mineral which is high in the scale

of hardness may have a comparatively low crushing strength and elasticity. Any increase in the percentage of this material will increase the hardness of the rock at the expense of strength and elasticity. Of course, the elasticity, hardness, and strength are not controlled by the one factor of abundance. A rock may consist entirely of the strongest minerals, and yet the size, manner of contact, and arrangement may be such that it will be one of the weakest.

TEXTURE OR STATE OF AGGREGATION

As outlined above the texture of a rock has reference to the size, shape, manner of contact, and arrangement of the mineral particles. The size of the particles affect the weathering of a stone by increasing the differential disintegration. When the mineral particles are large they disintegrate and weather out most easily, often leaving small depressions, on account of which the surface has a pitted appearance. The larger mineral particles have more pronounced cleavage cracks which increase the rate of weathering. Chemical agents have a better chance to operate and the stone is weakened throughout. Rocks which are composed of small mineral particles may have correspondingly small pore spaces, although the size of the pores is largely controlled by the shape and manner of contact of the grains.

The shape and manner of contact of the grains influence the strength and durability of the stone, as much perhaps as any of its other qualities. If the grains are close fitting the adhesion will be increased and the pore space decreased. When the grains are irregular in outline they usually interlock after the manner of dovetail work, which adds to the strength and lessens the pore space.

Upon the arrangement of the grains depends the laminated schistose, or cleavage structure in rocks. If the mica or other minerals are arranged with their longest axes in a common direction and concentrated along certain planes the rock will possess a capacity to part most readily in that direction and along those planes. The perfection of development of the parting capacity will be influenced also by the size of the grains.

The size, shape, manner of contact, and arrangement of the grains control the size of the pores and the percentage of pore space.[1] The porosity of a rock is an important factor, influencing the danger from alternate freezing and thawing of included water.

The pores, or spaces between the grains, which are connected in such a manner as to allow water to flow from one part to another have been divided for convenience into three classes.

The first class consists of small interspaces that exist between the grains of a rock, known as pore spaces; the second class consists of those openings which form along bedding, jointing, and fissile planes, known as sheet openings; the third class are those openings caused by the removal of several or many of the individual grains, commonly known as cavities, caves, or caverns. All of these openings frequently occur in the same rock.

Pores are ordinarily conceived of as being connected so as to form irregular-shaped tubes. Naturally they differ very greatly in size, depending upon the fineness and shape of the original particles composing the rock and the extent to which the interstices have been filled with secondary mineral matter. In the same rock all the pores are never of the same size, although they may have a general correspondence in size. The pores spaces are classified according to size into capillary and subcapillary. The capillary pores are the larger and the water which they hold is known as the water of saturation. Openings included in this class are over .00002 centimeter in diameter[2] If a rock containing capillary pores is allowed to drain off naturally, a portion of the water will escape, but another portion will

[1] It has been pointed out in another place that pore space in sedimentary rocks depends largely upon the size and shape of the grains and the amount of cement. In general this is true, but the cement itself becomes an individual grain, when once deposited in the interspace of a rock, and the shape and size of the cement grains should be considered. All particles of which a rock is composed should receive consideration as constituent grains of the rock.

[2] Metamorphism of Rocks and Rock Flowage, C. R. VAN HISE, Bulletin of the Geological Society of America, Vol. IX, p. 272.

remain which is known as the water of imbibition. The subcapillary pores are conceived to be of such a size, smaller than .00002 centimeter in diameter, as to contain only the water of imbibition.[1]

As in the case of pores, Professor Van Hise has classified sheet openings which occur along bedding, jointing, or other fissile planes, as capillary and subcapillary, including in the latter all such as are less than .00001 centimeter in thickness.[2]

The third class of openings consisting of cavities, caves, and caverns are a result of the removal of one or more of the grains of which a rock may have been originally composed. They occur most commonly in limestone or dolomite, although present in other less readily soluble rocks.

III. EXTERNAL CAUSES OF DECAY

In the selection of a stone for any purpose a consideration of the climatic conditions under which it is to be placed, is of very great importance. A uniform climate in which the temperature is always above the freezing point is most favorable to long life. A dry climate is conducive to stability, while a moist or humid atmosphere promotes decay. A stone which will withstand the vicissitudes of a moist, temperate climate, where there are long seasons of alternate freezing and thawing, short hot summers, and cold winters, must be of the most enduring kind. The well preserved condition of the monuments of Rome and other cities of the Mediterranean basin, after centuries of exposure, is not due so much to the inherent qualities of the stone, as to the warm, dry atmosphere. The obelisk of Luxor stood for centuries in Egypt without being perceptibly affected by the climate, but after only forty years of exposure in Paris it is now filled with small cracks, and blanched.[3] The same is true of the obelisk in Central Park, New York, from which many pounds of small fragments have fallen.[4]

[1] *Ibid.* [2] *Ibid.*

[3] A. A. JULIEN: Tenth Census, Vol. V, p. 370.

[4] J. C. SMOCK: Bulletin N. Y. Museum, Vol. II, No. 10, p. 385.

The external forces of destruction may be conveniently considered in two classes: (1) those that produce changes through mechanical disintegration and (2) those that produce changes through chemical decomposition. In the case of disintegration the adhesion between the particles or the cohesion of the particles themselves is overcome, and the rock ultimately crumbles into sand or powder. In the case of chemical changes the identity of the mineral particles themselves is destroyed, by the minerals being broken up into other compounds.

The following is a general classification of the agents of mechanical disintegration and chemical decomposition:

I. AGENTS OF MECHANICAL DISINTEGRATION

A. TEMPERATURE CHANGES.
   1. *Unequal expansion and contraction of the rock and its mineral constituents.*
   2. *Expansion occasioned by the alternate freezing and thawing of the interstitial water.*
B. MECHANICAL ABRASION.
   1. *Water.*
   2. *Wind.*
   3. *Feet.*
C. GROWING ORGANISMS.
D. CARELESS METHODS OF WORKING AND HANDLING STONE.

II. AGENTS OF CHEMICAL DECOMPOSITION.

A. WATER-SOLVENT ACTION.
B. CARBON DIOXIDE.
C. SULPHUROUS ACIDS.
D. ORGANIC ACIDS.

Temperature changes.—Injuries to a stone through changes in temperature are occasioned in two ways: (1) By the unequal expansion and contraction of the rock and its mineral constituents, and (2) through expansion due to the alternate freezing and thawing of the interstitial water.

Unequal expansion and contraction of the rock.—The heat conductivity of stone is very low. A stone a few inches in thickness may be heated on one side to a temperature sufficiently high that it will not bear handling, while on the other side the stone may be comparatively cold. The actual expansion of different kinds of stone has been experimentally determined by W. H. Bartlett,[1] in which he obtained the following results:

Granite, .000004825 inch per foot for each degree F.
Marble, .000005668 inch per foot for each degree F.
Sandstone, .000009532 inch per foot for each degree F.

The diurnal changes in temperature in this latitude are often as much as 50° F., while the annual variation in temperature exceeds 150° F. A difference of 150° F. would make a difference of one inch in a sheet of granite 100 feet in diameter.

Each mineral of which a stone is composed has a different rate of expansion. Whenever a stone is heated each particle presses against its neighbors with almost irresistible force. When cooling begins, contraction sets in which initiates stresses pulling the individuals apart. The inequalities in the rate of expansion of the different mineral particles initiate stresses in rocks having a heterogeneous composition, which tend to separate the individual minerals from their neighbors. The result of these alternating temperatures is to weaken the rock and produce small cracks into which water may percolate or roots descend.

Besides the unequal expansion and contraction of the mineral particles, there is an unequal expansion and contraction between the different laminae or hypothetical layers of the rock which are near enough to the surface to be affected by the atmospheric temperatures. The layer at the surface suffers the greatest change in temperature, and is therefore most affected. Each succeding layer is less affected until a point is reached where there is little or no change in the temperature the year around. Owing to the rapid diurnal changes in temperature in some regions forces are constantly at work tending to separate the superficial stratum from those immediately below.

[1] American Journal of Science, Vol. XXII, 1832, p. 136.

The igneous rocks on account of their heterogeneous mineralogical composition, interlocking character of the mineral individuals, and difference in size, are more liable to injury from the diurnal changes of temperature than are the unaltered sedimentaries.

Investigation shows that, in arid regions, very great work is accomplished simply through expansion and contraction due to diurnal temperature changes. Merrill, in his "Rock Weathering," cites an instance in Montana where he found "along the slopes and valley bottoms numerous fresh, concave, and convex chips of andesitic rock, which were so abundant and widespread as to be accounted for only by the diurnal temperature variations. During the day the rocks became so highly heated as to become uncomfortable to the touch, while at night the temperature fell nearly to the freezing point."[1] Livingstone reports the temperature of rock surfaces in Africa to rise as high as 137° F. in the day, and cool off so rapidly by night as to split off rocks weighing as much as 200 pounds. The expansive force of heat is well shown in many of the limestone quarries in Wisconsin, where beds from five to six inches in thickness are for the first time exposed to the heat of a summer's sun. These thin beds become heated throughout their entire thickness and arch up on the floor of the quarry, generally breaking and completely destroying the stone.

Many buildings show the effect of weathering on the side exposed to the direct rays of the sun, while the sheltered side remains uninjured. The only rational explanation for this is found in the diurnal temperature changes. Ordinarily the movements due to temperature changes are necessarily small, but after centuries of time they must invariably result in the weakening and final disintegration of the stone.

Expansion occasioned by the alternate freezing and thawing of the included water.—The effects of diurnal temperature changes as described above, are small when compared with the action of continued freezing and thawing on a rock saturated with water.

[1] GEORGE P. MERRILL: Rocks, Rock Weathering, and Soils, p. 181.

The expansive force of freezing water is graphically described by Geikie "as being equal to the weight of a column of ice a mile high, or little less than 150 tons to the square foot." One centimeter of water at 0° C. occupies 1.0908^{cm} in the form of ice at 0° C. It is this expansion of about one tenth that does the damage when confined water solidifies.

Water finds its way into the rocks through openings or hollow spaces which are everywhere present. Where the pores are large the stone contains water of saturation which is given off with comparative readiness, but the nearer the pores or sheet cavities approach those of subcapillary size, the greater is the tenacity with which the water is retained. One can readily understand how the particles composing a rock may be so closely fitted together, that the pores will be mainly of subcapillary size. Such a rock will contain only the water of imbibition which will be given off very slowly, on account of which the attendant dangers from freezing will be increasingly great. In general it may be said that the danger from freezing will be increasingly great as the pores approach in size those of subcapillary dimensions.

Two rocks, one of which has very minute interstices and the other of which has large pores may have a capacity to absorb equal amounts of water. The former, however, will be in much greater danger from alternate freezing and thawing. Of two equally saturated rocks, one with 10 per cent. and the other with 3 per cent. of pore space, in which the pores are of equal size, the more porous one will be in greater danger of freezing. The percentage of the pore space that is filled with water will also condition the results of freezing. If two thirds of a rock is saturated greater injury will result from its freezing than if only one third were saturated. If none of the pores are more than nine tenths filled with water, the effect of freezing will be nothing, because the increased bulk of the frozen water will no more than fill the spaces between the grains.

The amount of water contained in the pores at a given time depends, of course, upon the amount of water initially absorbed,

the time that has elapsed since absorption, the condition of the atmosphere, the size of the pores, and the position of the stone. It is only in exceptional cases that the stone in the wall of a building is saturated. However, if the pores are of greater than subcapillary size the water of saturation will, as a rule, be quickly removed, except in the lower courses below the water line.

It would, therefore, appear that the most important factor in estimating the danger from freezing and thawing, is the size of the pore spaces, which controls the rate at which the interstitial water is given up. The second factor of importance is the amount of water contained in each of the pores at the time of freezing. The third and last in importance is the total amount of pore space.

T. S. Hunt, in "Chemical and Geological Essays," says: "Other things being equal, it may properly be said that the value of a stone for building purposes is inversely as its porosity or absorbing power." This statement has been quoted by various authorities, one of whom says: "Other things being equal, the more porous the stone the greater the danger from frost." The mistake has often been made of estimating the danger from freezing by the capacity which a stone has to absorb water. Likewise the capacities which two stones have to withstand weathering are constantly being compared from the standpoint of the ratios of absorption. Such estimates and comparisons are very misleading, for one should not only know the capacity which a stone has to absorb water, but he should, above all, know and consider the relative size of the pores.

The injurious effects of the freezing of the "quarry water," as the interstitial water is called by quarrymen, has long since been known to contractors, who generally refuse to accept stone, especially sandstone, which has been exposed to the action of freezing before being seasoned. Where it is possible, quarrymen sometimes flood their quarry during the winter months, in order to protect the stone immediately at the surface.

The openings formed along bedding, jointing and other fissile planes, permit a freer circulation of water than the pores in the

rock. After an abundant fall of rain or when the snow melts in the spring, the cracks, crevices and pores in the rocks cannot carry away the water nearly as rapidly as it collects in these passages at or near the surface. If the temperature at such a time is fluctuating between freezing and thawing, the water will be alternating in a liquid and solid state. As the water congeals again and again the walls are pressed farther and farther apart. The ice acts as a wedge which automatically adjusts itself to the size of the crack, until the opening is sufficiently wide and deep to allow the free passage of the water. Not only are the cracks and crevices very much enlarged and extended through the stresses exerted by the solidification of the water but the stone is in itself materially weakened.

The danger from the freezing of water collected along parting planes must not be confused with the danger attendant upon the freezing of water which fills the pores of the rock. The compact, thoroughly homogenous rocks, without bedding or other parting planes, whether sedimentary or igneous, are in less danger from alternate freezing and thawing than those in which these structures occur.

Alternate freezing and thawing of the included water has been one of the most potent causes for the decay of building stone, more especially that stone which is bedded or otherwise laminated. The most disastrous results occasionally occur from using stone which has not been properly seasoned, and in cases where the stone has been laid on edge instead of on the bed. In the first case the stone is materially weakened throughout by freezing, while in the latter exfoliation or scaling is liable to ensue. The most trying place in a building, in which to place a stone, is at the "water line," where saturation is most common and the greatest alternations of freezing and thawing occur. The conditions are more severe in the case of bridge abutments and retaining walls than elsewhere. In bridge abutments the courses of stone at the level of the water are often badly shelled and broken, while the stone above and below is scarcely injured. It is not uncommon to observe all the courses of a retaining wall

in a dilapidated condition after it has been built a comparatively few years. When the snow melts in the spring the water sinks into the ground and issues through every crack and crevice in the wall. As it collects along these fissile planes it freezes and wedges apart the laminæ of the rocks.

Because the sedimentary rocks more frequently have parting planes than the igneous, they are as a class more apt to suffer from alternate freezing and thawing. On the other hand the sedimentary rocks are sometimes as free from parting planes as the igneous, and are accordingly in as little, or even less, danger from freezing.

The openings known as caves, caverns, and cavities need not occupy our serious attention. Cavities occasionally occur in both sedimentary and igneous rocks used as building stone, but mainly in the former. They do not increase the danger from freezing, owing to the fact that they are seldom filled with water when near the surface. They weaken the rock slightly and often occasion a roughness of the face when they occur at the surface. The cavities are often partly filled with impurities, such as pyrite, which may injure the rock, through the readiness with which they decompose.

From the foregoing we may conclude that an ordinarily well cemented sandstone, which is free from parting planes or stratification, and in which the pores are of greater than subcapillary size, is best suited to withstand alternate freezing and thawing when placed in the wall of a building; assuming that the original strength of the stone is sufficient for the position which it occupies in the wall.

Mechanical abrasion.— One of the most important agents of disintegration in nature is mechanical abrasion, but the rôle which it plays in the destruction of artificial structures is not nearly as important as that of certain other agents.

Mechanical abrasion is accomplished mainly by wind, running water, and shuffling feet working in conjunction with the other agents of disintegration. The beating of the rain against the stone wall may overcome the adhesion between the rock

particles, separate them from one another, and carry them away. These particles may, in turn, as they are carried down the side of the building, wear off other particles, and so on until the bottom is reached. The effects of drifting sand, that are such conspicuous features of the arid regions, are very slight in the temperate zone in which we live. Drifting sand contributes an almost insignificant part to the whole process of disintegration. J. C. Smock, in his report on the building stone of New York, mentions the fact that the ground glass character of many of the window panes in some of the older houses of Nantucket are due to driven sand. The windward sides of many of the monuments in the older eastern cemeteries have lost their polish, while in some cases even the lettering has been destroyed by this same agent. The monuments in the cemeteries of Wisconsin which are located in sandy regions are beginning to show the effects of wind-blown sand. The polish is dulled and the lettering is becoming indistinct.

Besides being subject to the action of wind-blown sand and rain, stone is often used in places where it is abraded by thousands of feet passing over its surface. There is a great difference in the capacity which different stones possess to withstand abrasion. Sidewalks, pavements, and steps may be seen in every city which are more or less worn by constant shuffling of feet over their surfaces.

Growing organisms.—It is a very common occurrence to find lichens and algæ covering the surface of a rock in a quarry. Trees may also be observed sending their roots deep into the crevices and cracks of the rock, and by their growth and expansion huge blocks are often broken from the parent mass. In some of the very soft rocks the writer has observed the finer rootlets ramifying through the body of the rock itself, destroying the adhesion which bound the particles together. Decaying plants are also known to give off organic acids which aid in the decomposition of the rock. Fungi and algæ often attach themselves to the stone, frequently almost entirely covering the exposed surface. The most common form of plant growth

occurring thus is the lichen, which often covers the surface of the rock after the manner of a mat, thereby exerting a protective as well as a destructive influence. The covering which they form serves as a protection against the atmosphere, while the acids incident upon their decay and the mechanical effects of their rootlets penetrating between the grains are a slow cause of disintegration. Algæ are also common, and often occur on the damp parts of a wall, causing discoloration through their own decay and the lodgment of fine dust particles. The effect of allowing creeping vines, such as ivy, to cover the walls of buildings is picturesque, but the practice is certainly injurious to the life of the stone.

Careless methods of working and handling.—The natural forces of destruction have been greatly accelerated, either through the ignorance of quarrymen and their total disregard for proper time and methods of quarrying, or through the carelessness of workmen in cutting, carving, and laying the stone used in building construction. There are probably thousands of buildings, constructed out of stones, the lives of which have been shortened at least one half by improper methods of quarrying and handling.

Quarrymen have been found moving stone with heavy charges of powder, or even dynamite, expecting to obtain dimension stone for building purposes. The heavy charges of powder not only destroy a large amount of stone, but they also shatter the cement and produce incipient joints in the blocks which may accidentally remain in dimensions sufficiently large for building purposes. The destruction of the cement and the production of incipient joints not only weaken the rock, but also facilitate the entrance of water, with the attendant dangers from freezing, with which we are already familiar. This method of quarrying not only materially lessens the value of the salable stone, but hundreds of tons of otherwise marketable stone is absolutely destroyed. The use of heavy hammers and sledges in splitting the stone, by striking continuously along one line, shortens the life of the stone in the same manner as heavy blasting.

Much care should be exercised in quarrying stone in order to prevent these unnecessary injuries. So far as practicable, quarrymen should take advantage of the natural joints. Whenever blasting becomes necessary, the Knox system of small charges, properly distributed, is reported to be the least injurious of any method yet employed. The channeling machine, however, is the best method of reducing the stone to dimensions that can be easily handled. Especially in working sandstone and limestone this machine can be employed to advantage.

The time of cutting and dressing stone may also influence in a small way its life It is generally known that during the process of seasoning the water which comes from within the rock evaporates and deposits mineral matter which forms a crust on the surface of the stone. This crust may be formed entirely by the evaporation of the original interstitial water, or it may be added to by water which has been soaked into the stone at a later period and been subsequently brought to the surface.[1] That water, which has been called the water of imbibition, probably carries a much larger percentage of mineral matter in solution than the water of saturation. The water of imbibition is the last of the quarry water to leave the stone, and therefore the crust is not likely to be well formed until the rock has been thoroughly seasoned. If the stone is to be seasoned before being placed in the wall, it is advantageous to have it first cut, dressed, and carved. Not only is it advantageous to observe this rule from the standpoint of future durability, but also from the fact that the stone often works much more readily when first quarried than it does after it has been seasoned. After a crust has once formed it should not be broken, because the softer rock underneath, when exposed at the surface, will disintegrate much more rapidly. For these reasons most stone should be worked and finished, ready for laying in the wall, before it has been thoroughly seasoned.

[1] The addition through saturation and evaporation after the quarry water has been driven off is probably an almost unappreciable amount, depending upon the amount of mineral matter originally in the water.

The manner of dressing a stone also influences in a small way the length of its life. A stone which has polished surfaces sheds water much more quickly and is disintegrated much more slowly than one with rough surfaces. The stone with rough surfaces has many crannies and crevices, in which the water collects and is finally absorbed. Sandstone which has been hammer-dressed is liable at first to disintegrate faster than that which has been sawed, due to a weakening of the cement by the impact of the hammer. In general, it may be said that polished and sawn surfaces shed water most readily, while those that are rock-faced or hammer-dressed, on account of their rough exterior, absorb a considerably larger percentage of the water which falls on their surfaces.

Before a stone is used in the construction of a building it is safer to have at least the water of saturation driven off. As a rule quarrymen are acquainted with the effects of frost upon stone in which the water of saturation still remains, and observe the necessary precautions. There are quarrymen, however, interested solely in the disposition of their stock, who impose upon the ignorance of the public by selling stone which has not been seasoned. Stone should be seasoned not only to escape the danger from freezing, but also to insure safety in handling and laying.

The exfoliation of sandstone in the large eastern cities has been mainly attributed to the fact that much of the stone has been laid on edge instead of on the bed. Laying stone on edge has been practiced at all times, owing to the greater readiness with which stratified or schistose rocks can be dressed along the bed. The greatest tendency to lay stone on edge is encountered in veneer work, but is occasionally met with in heavy masonry.

If the parting planes, which ordinarily furnish the easiest paths for percolating waters, are normal or inclined to the surface of the earth, they will admit the passage of water much more readily than if they are parallel. Thus if a block of stone is placed on edge in a wall, there will be greater danger from the

freezing of the included water than if it were laid on the bed. In case the stone is laid on edge, the pressure required to split off lamina will ordinarily be much less than if the stone is laid on the bed. In the first case the force occasioned by the freezing of the water which collects between the layers is augmented by the superincumbent pressure of the wall. If the stone is laid on the bed, the water is less apt to penetrate along the parting planes, and even though it should circulate with equal freedom in this position, the superincumbent pressure of the wall would tend to force the expansion in directions parallel to the bedding.

Furthermore, when stone is laid on edge the difference in texture of the various laminae are much more strikingly emphasized than where the stone is laid on the bed. When laid on edge the different blocks, as a whole, will exhibit different rates of wear, instead of the minor inequalities ordinarily shown by the different laminae when the block is laid on the bed.

In important structures one ought to avoid laying any stone on edge which shows stratification or schistosity for the reason that in this position it is inherently weaker and permits a more ready absorption of water, with the attendant dangers from alternate freezing and thawing.

AGENTS OF CHEMICAL DECOMPOSITION

In artificial stone constructions the decomposition of the mineral constituents of a rock proceeds much more slowly than disintegration. The forces which are at work breaking down the chemical compounds have a much greater task to perform than those which have simply to overcome adhesion and cohesion.

Water.—The active agent producing chemical changes in the rock is water. Water generally contains in solution, besides mineral salts, one or more acids, either sulphuric, sulphurous, carbonic, or organic. Thus the water is often a very dilute acid solution. As it percolates through the rocks it dissolves small quantities of mineral matter in one place and deposits it in another. Through these agents the minerals composing the rocks of both the igneous and sedimentary series are decomposed, and transfers of large quantities of mineral substances take place.

In the case of building stone the chemical decomposition of the minerals is so exceedingly slow that it seldom affects the strength or life of the stone after it has been placed in a building. Only in the case of limestone, dolomite, or marble, or where iron sulphide or iron carbonate occur in other rocks, is any material deterioration noticeable.

Sulphurous acids.—In the case of decomposition of iron sulphide, in the presence of moisture, the formation of iron oxide is the most conspicuous, although not the only result. The decomposition of the sulphide produces sulphurous and sulphuric acids which, in the case of dolomite, act upon the magnesium carbonate, producing magnesium sulphate, which is often brought to the surface and deposited as an efflorescence or incrustation.

The sulphurous and sulphuric acid gases are mainly present in the atmosphere of large cities where there is a large consumption of bituminous coal. The action of these acids is largely increased if the atmosphere contains a considerable amount of moisture. In London, where fogs predominate and the consumption of soft coal is very large, there seems to be little question but that the effect of these gases is worthy of careful consideration. But in the United States, with the exception of a few of the larger cities, the influence of these agents is comparatively small and needs but a passing mention.

Carbon dioxide.—Wherever water heavily charged with carbonic acid gas is passed through calciferous rocks, more or less of the calcium carbonate is dissolved, lessening the adhesion between the different particles and weakening the rock. In nature the results of this process are very great, but the carbon dioxide has scarcely any appreciable affect on the durability of stone in the walls of a building.

Organic acids.—The influence of organic acids resulting from decaying organisms on the life and strength of a rock, especially in the walls of buildings, is so slight as to barely warrant mention.

E. R. Buckley.

Editorial

The meeting of the Committee on Rock Nomenclature, appointed by the International Geological Congress, which was held in Paris last October, failed to elicit concerted action on the part of petrographers. Only two reports were received from committees representing different countries. They were from Russia and France, and will be transmitted to the Congress. The small attendance at the meeting, the wide divergence of views indicated by members expressing themselves by letter, and the desire of independence manifested by all, make it impossible for the committee as a whole to transmit a report to the congress. Each petrographer is expected to present his views in his own way at the coming meeting in Paris.

Apparently there has been no progress toward harmony of nomenclature or of rock classification. There is still a wide divergence of ideas concerning rocks themselves and the methods of dealing with them. While this is to be regretted, it is not to be wondered at, considering the abstract petrological, as well as the anthropic, elements involved in the problem. However, there are indications of advancement along more or less converging lines that will eventually unite. In the meantime every petrographer is a law unto himself, as is evident from articles recently published in this Journal and elsewhere.

Professor Hobbs, in his discussion of this subject in this volume of the Journal, has laid special emphasis on the value of diagrams in conveying ideas of relative quantities of chemical constituents of rocks, availing himself of Brögger's modification of Michel-Lévy's diagrams. The importance of such devices for expressing relative quantities and for permitting ready comparison of many variable factors in an intricate problem cannot

be overestimated. They not only fix in an easily comprehended form facts already vaguely apprehended, but often suggest relationships not previously suspected. With all machines the product turned out depends on the material operated on. And while the machine itself may be perfect, the product may be open to criticism.

The diagrams in question tend to give more definite impressions of the relative quantities of the chemical elements in rocks than are obtained from the usual statements of analyses. But, if instead of actual rock compositions there is substituted an average of various rocks, it is clear that there is danger of placing too much value on the apparently definite expression conveyed by the composite diagram. Everything depends upon what rocks have been grouped together. Defects in grouping vitiate the diagram. For this reason it is desirable to distinguish between the use of graphical methods of presenting an assemblage of diverse quantities, which is highly commendable, and the practice of averaging diverse quantities, which is open to serious criticism.

J. P. I.

Reviews.

Om klimatets ändringar i geologisk och historisk tid samt deras orsaker. [On Changes of Climate in Geologic and Historic Time and their Causes.] By Nils Ekholm, *Ymer*, Årg. 1899, H. 4, pp. 353–403. Published by Svenska Sällskapet för anthropologi och geografi, Stockholm.

The first section of the paper discusses, in a general way, the causes of telluric temperature changes. The author states at the outset that the temperature of the earth depends upon the ratio of the amounts of insolation and radiation. He thinks that the solar radiation has very likely not been subject to any considerable changes during the time the earth has been an abode of life. But the transparency of the atmosphere to different kinds of heat rays, and hence also to radiation, has, no doubt, varied greatly and caused the great changes in climate known to geology. Only in the second place would he put the eccentricity of the earth's orbit and the inclination of its axis as a cause of climatic changes. He does not think that the eccentricity of the earth's orbit has caused any climatic variations which have left traces known to geologists. But the variations in the inclination of the earth's axis have caused changes of considerable magnitude in the polar regions, and in the adjacent zone, at least as far down as the latitude of 55° in the northern hemisphere.

The old notion that the internal heat of the earth has appreciably affected climatic conditions in geological time must be set aside. The earth was, no doubt, at one time in the same condition in which we now find the planet Jupiter. There was a dense atmosphere filled with steam. After the temperature of this atmosphere of the cooling globe sank below the boiling point of water its vapor rapidly (in a few hundred years) condensed to a boiling sea. While the convection of this sea was in effective action, the temperature of the sea bottom, the upper crust of the earth, was rapidly lowered, which caused the outer crust to crack open as it contracted relatively more rapidly than the interior. This process went on until the radiation of the crust outward

(which grew less and less) equaled the conduction from below. Then there was a resting time. The cracking ceased. Later the conduction of heat from the interior to the crust was smaller in amount than the radiation from the surface. As a result lateral pressure was developed and caused the rise of the land above the sea here and there in folds.

The paper then proceeds to offer proof that the conduction from the heated interior is vanishingly small at present compared with insolation, hence it can cause no appreciable rise in temperature now.

There follow some paragraphs on geological time and the probable age of life on the earth. The author quotes some computations "made by T. Mellard Reade and communicated by Chamberlin" relative to the age of the sea (JOURNAL OF GEOLOGY, Vol. VIII, p. 572). The computations referred to were made by Chamberlin, though this is not explicitly stated in the paper quoted. The estimates made by Nathorst, Phillips, and Geikie are given. The calculations of Lord Kelvin are also discussed. He is said to have made use of such assumptions that the results attained can hardly be regarded as anything more than a mathematical exercise without bearing on the physical problems involved. It is maintained that there are no physical data disproving the high estimates of geological time favored by geologists and biologists.

The headings of the third part of the paper may be rendered as follows: Insolation nearly constant during geological time; changes in the quantity of carbon dioxide in the atmosphere the principal cause of the great climatic changes; the cause of the change in the quantity of carbon dioxide in the atmosphere. The author refers to Lord Kelvin as having made calculations on radiation from the sun, and having reached the conclusion that the mean temperature of the sun has been constantly rising. The author has carried out further these computations in a paper just submitted to Kongliga Svenska Vetenskaps Akademien, entitled *Ueber den Energie-Vorrath, die Temperatur und Strahlung der Weltkörper*, and finds that the rise in the mean temperature of the earth has been compensated by the diminution in the surface of the sun and also by the decreasing efficiency of the convection currents from the interior to the exterior of the sun. Possibly the radiation was less than it is now at the time when the sun's radius was sixty times its present length.

Then follows an account of the researches of Arrhenius. From these some conclusions are drawn. It is estimated that a diminution

of the carbonic acid in the atmosphere to two thirds of its present amount would probably reduce the temperature of the polar regions by 5° C., and a tripling of the present amount would increase the temperature there by 18° to 20° C., the temperature of the Cretaceous period. A few paragraphs are devoted to discussing the amount of carbon dioxide, the cause of its fluctuations. Using a commercial simile, he remarks that the exchanges between the CO_2 consuming processes and the CO_2 yielding processes are carried on with a very small capital, and hence they are proportionately rapid, and as a result are subject to great and fortuitous changes. New carbonic acid is furnished by volcanic activities (Chamberlin, JOURNAL OF GEOLOGY, Vol. VI, p. 611), and by meteors bringing it into the upper atmosphere. Pursuing his commercial simile he remarks that the reserve fund is in the sea. Chamberlin is again quoted on the effect of lime-secreting organisms in the sea and as to the chemical condition of the carbonic acid in the sea.

Over the first ocean the atmosphere very likely became, as time went on, more and more impregnated with carbon dioxide. This is supposed to have taken place after the conduction of heat from the earth's interior had ceased to have climatological importance. This increase of carbon dioxide is believed to have resulted in the rise of temperature which affected the crust of the earth. The temperature of the early Cambrian age is hypothetically placed at 20° C., with a rise during the period of 10° higher temperature. It is estimated that this rise of temperature would cause folds four kilometers in height, if the expansion were concentrated so as to have caused rising in any single place. In a similar way mountains are held to have been formed in the Carboniferous age. By erosion large amounts of the carbonates were carried to the sea, favoring the life of carbonate-secreting animals. By the increase of land and of temperature the consumption of CO_2 was increased, resulting in the withdrawal of much of it. Thus the cold of the Permian age was brought on.

The progressive cooling of the surface temperature during the Permian age is also discussed. A change from 30° to 10° C. is assumed. This brought about a contraction of the outer shell relative to the inner kernel of the earth. The computed relative shrinking of the outer shell is 12.8 kilometers. This shrinkage brought on extensive cracking and volcanic activity, and thus led to an increased production of carbon dioxide. Thus warm climate again resulted, probably lasting

during the Cretaceous and into the Tertiary period. A subsequent period of folding and withdrawal of carbonic acid resulted in the great ice age. After several less well-known climatic changes — some geologists count as many as six different ice periods — the recent period finally arrived with its temperate climate, in which we still live.

To the fundamental causes here discussed as affecting the climatic changes of long duration, a secondary cause may be added, as pointed out by Chamberlin, namely, the continued erosion and denudation of the continents by precipitation. It is evident that this cause intensifies the climatic conditions between cold and warm periods. In a note (p. 375) the author leaves it to the future to decide whether the interglacial periods are due to changes in the atmosphere, or to changes in the inclination of the earth's axis.

Since the cooling of the polar regions of the earth have, on the whole, always been in advance of the cooling of the tropical and temperate zones, our greatest mountains lie in these latter zones. The polar caps have attained a greater solidity and resistance to pressure, and thus the folding has been mostly transferred to other regions.

The sea has served as a great moderator of the climatic changes of long period. *The cause of the latter must be sought in the alternate contraction and expansion of the earth's crust following changes in the mean temperature of the atmosphere.*

The fourth part of the paper has for its subject *the changes in the inclination of the earth's axis to the ecliptic and its influence on climate.* Here is first given a summary of the evidence of changes in the flora and fauna of northern Sweden, since the ice left the peninsula. Since the time of the "Oak zone," the average temperature has fallen 2° C., judging by the fossil distribution of Hazel. Possibly the winter temperature was but little different from the present. Accepting the archeologist's figures as to the time of the appearance of paleolithic man in Sweden, 7000 to 10,000 years back, the highest temperature of the climate of Sweden seems to have occurred at that time. The author then proceeds to show that the Quaternary changes of climate can be readily and fully accounted for by the "long-periodic" changes in the inclination of the earth's axis. He has tabulated Stockwell's calculations (p. 381). These show the inclination to have been small about 9000 years ago, and that it has been increasing since then. He presents a calculation of the length of the mid-summer day (the sun not setting) for Karesuando, the northernmost meteorological station

in Sweden, at the latest minimum and maximum of inclination, respectively 9100 and 28,300 years ago, thus:

28,300 years ago - -	38 days
9,100 years ago - - -	62 days
At present - - -	54 days

Then follow tables showing calculated temperatures (in terms of excess and deficiency compared with the present) for different latitudes during the months of the year at the last maximum (28,300 years ago) and the last minimum of inclination (9100 years ago) north of 80° N. latitude. There was, 28,300 years ago, a deficiency of 5° C. In Sweden the deficiency was from 3½° to 2° C. These figures are all for the summer months. The author is uncertain as to the winter temperatures. In Sweden these would perhaps depend on the gulf stream, as at the present; 9100 years ago the summer heat was 2° to 1.3° C. higher than now, while the winter temperature is uncertain. A time with hot summers occurred 48,000 years ago. Geologists know of no other period of greater heat than the present, except the one 9000 years ago, *since the end of the last glaciation*. The end of the ice age, hence, cannot have occurred earlier than 50,000 years ago. Possibly it is later, but the greater summer insolation 48,000 years ago may have helped in melting the ice.

The last section of the paper relates to *climatological changes in historic time, especially in northwest Europe*. The author discusses recorded observations on the forming and thawing of ice on various Scandinavian waters, ancient stock-raising in Greenland, grape culture, etc., and concludes that the winters have grown milder and the summers cooler during the last 300 years. Some conclusions are drawn from a study of weather records made by Tycho Brahe. A comparative table of snow precipitation for Brahe's time and the present is given as follows.

PER CENT. OF DAYS WITH SNOW OUT OF TOTAL DAYS OF PRECIPITATION.

Years	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.
1582–1597 (Time of Brahe) -	3	14	38	45	75	63	21
1881–1898 (Present) - -	2	16	37	48	53	46	19

By comparing this table with current temperature, he finds that it is likely that 300 years ago February was 1.4° C. colder than now, March 1° C. colder, and the other months differed either way by less than .2° C.

Finally the author discusses secular temperature changes as indicated by thermometric measurements made in the last 100 or 150 years, and concludes that at Haparanda, Stockholm, and Lund, in Sweden, the January temperature has risen during this time 1° C., while that of August has become somewhat cooler. At Lund, April, June, September, and October temperatures have remained unchanged.

The paper contains five figures. One of these shows the fossil and present distribution of Hazel in Sweden.

This article is particularly interesting to one who has previously read Chamberlin's papers on the same questions. There are several points of coincidence in the two. One of the authors is a meteorologist, the other a geologist, by profession. On the main cause of long-periodic changes of climate both agree. In accounting for minor details the geologist favors meteorologic causes, while the meteorologist seems inclined to accept, with a modification, a hypothesis which has been quite generally favored among geologists.

J. A. UDDEN.

Sveriges temperaturförhållanden jämförda med det öfriga Europas. [The Temperature Conditions of Sweden compared with those of the rest of Europe.] By NILS EKHOLM, *Ymer*, Årg. 1899, H. 3, pp. 221–242. Published by Svenska Sällskapet för antropologi och geografi, Stockholm.

The only portion of this paper that has obvious geological bearing is the statement that the temperature conditions of Sweden, especially the cold winters which sometimes occur, are to be explained rather by exceptional conditions favorable to radiation than by cold winds coming from Siberia. The author shows, among other things, that the recurrence of cold winters in Sweden exhibits a quite definite periodicity of five and two thirds years, or half the length of the sun-spot period.

J. A. UDDEN.

Physiography of the Chattanooga District in Tennessee, Georgia, and Alabama. By C. WILLARD HAYES. United States Geological Survey. Part VII, Annual Report, 1897–8.

In this report the author has done what Gilbert did in his "Geology of the Henry Mountains," namely, has made a study of a region

where the conditions are more or less simple, with a view of establishing principles which may be used in regions of greater complexity. The region concerned is situated in southeastern Tennessee, northeastern Alabama, and northwestern Georgia. It is bounded by the meridians of 84° 30′ and 86°, and by parallels of 34° and 36°, and comprises nearly 12,000 square miles.

The problems considered are as follows: (1) The forms assumed by maturely adjusted streams in a region where the strata are faulted and folded, and where metamorphism has so affected the rock that the original differences have been diminished, leaving a somewhat homogeneous series; (2) the forms assumed by streams when the strata are practically horizontal, and where the beds vary greatly in hardness; (3) the processes by which consequent drainage in a region of folded strata is transformed into subsequent drainage, with the development of anticlinal valleys and synclinal ridges; (4) the present altitude of former base-levels and the determination of the deformations which the region has suffered in recent geological time. These problems are considered under two main heads, namely, "Geomorphology" and "Geomorphogeny."

The Chattanooga district embraces a part of each of the five natural divisions into which the southern Appalachian province has been divided by Powell.[1] Within this region Hayes finds three types of topography: (1) The Western type, including the Cumberland plateau and the Highland Rim, a part of the interior low lands; (2) the Central type, and (3) the Eastern type.

(1) The first or Western type is separated from the other divisions by the Cumberland escarpment, which forms the eastern boundary of the Cumberland plateau. In the northeastern portion of this district streams have hardly begun to cut in the plateau, while to the south and west only remnants of the plateau remain, each remnant retaining the characteristics of the original highland. The plateau is about 1800 feet above sea level, the Highland Rim about 1000 feet, while the low lands, which stretch northwestward to the Ohio River, have an altitude of but 600 feet. Thus it is seen that the Highland Rim is a terrace between the Cumberland plateau and the lowland. (2) The Central type is that of the Great Valley, in which there are three levels or sets of levels. The valleys of the Tennessee and the Coosa rivers are from 600 to 700 feet above sea level. One series of valley ridges reaches

[1] Physiographic regions of the United States: Nat. Geog. Mag., Monograph No. 3.

altitudes of from 900 to 1100 feet, and another altitudes of from 1500 to 1700 feet. (3) The Eastern type comprises the Unaka Mountains and the western portion of the Piedmont Plain.

The formations of this region are divided into two groups: (1) The unaltered sedimentaries which are of varying degrees of hardness and solubility, and (2) the metamorphic and igneous rocks.

The twenty-three formations of the Paleozoic are divided into five subgroups: (1) The lowest six Cambrian formations consist of conglomerates, quartzite, and siliceous shales, and are nearly insoluble. These form the rocks of the Eastern division. (2) Ten Cambrian and Silurian formations, composed for the most part of limestone and shales, are relatively soluble. These occupy the greater part of the Valley or Central division, while a few beds of sandstone and the Knox dolomite give rise to the valley ridges. (3) The Upper formations of the Silurian and the formations of the Lower Carboniferous are the rocks which form the Highland Rim, and also some of the valley ridges. (4) On account of their solubility, the Lower Carboniferous series gives rise to the characteristic topographic forms in the Western division. (5) The durable Coal Measures conglomerates cap the Cumberland plateau and have occasioned the preservation of large areas of its surface.

The second group of rocks, that is, the igneous-metamorphic group, comprises, (1) the feldspathic (easily eroded) rocks which form the larger part of the Piedmont plateau, and (2) the non-feldspathic (resistant) rocks which have given rise to the irregular topography of the Unakas.

In this region Hayes makes out three peneplains or base levels, namely, the Cumberland base level, the Highland Rim base level, and the Coosa base level.

The altitude of the reconstructed Cumberland base level at its southern edge is about 1200 feet. From this altitude it increases to a height of 2000 feet in the central part, and decreases again to 1600 feet along its southern and eastern edges. This gives a gradient of ten feet per mile from the edges to the center, which is steeper than a base level grade should be, and, besides, no base level tract should have such a shape unless drainage radiated from its center, and this does not seem to have been the case. Hayes explains the present form by the hypothesis that in being elevated to its present position the base leveled region was warped into the form of a low dome. Upon

the peneplain are a few remnants above the general level. The Cumberland base-leveling epoch came to an end with the uprising at the end of the Cretaceous.

The Highland Rim is the peneplain next below the Cumberland. It retains a very uniform height, the difference between the northern and southern edges being but little more than existed during the period in which it was base leveled. Upon this plateau also there are monadnocks which represent areas of more resistant rocks.

The altitude of the lowest and youngest peneplain is 700 feet at the south and 800 feet at the northern edge. Here, as upon the other plateaus, there are considerable variations in altitude in different parts of the peneplain. These should not be taken as indicating distinct base levels, but simply the influence of local conditions.

Hayes considers two hypotheses in explanation of these peneplains, namely, subaërial denudation and marine denudation. He finds support for the former only.

The streams of this region belong to three distinct river systems, the Cumberland, the Tennessee, and the Coosa. They are the main agents which have shaped the present topography. There have been periods of stability and relative inactivity, alternating with great revolutions. It is hard to follow all these changes in detail, for the history of each change is in some measure obscured by that of the next. The first cycle of erosion resulted in the formation of the Cumberland peneplain. This cycle began when the land was raised at the end of the Carboniferous, and ended with the uplift closing the Cretaceous. This long period of erosion was not a single cycle, but was composed of a number of more or less distinct cycles, the evidence of which remains even to this day. Hayes has worked out the general courses of the Paleozoic streams in some detail, but no statement would be intelligible without the maps.

When the Cumberland peneplain was raised and warped, and the second cycle of erosion inaugurated, there were signs of activity all along the line. The sluggish streams began again to cut their beds and to fight for the mastery of favorable positions. The development of new streams at the expense of the old, changes in the direction of drainage, and final, almost perfect, adjustment of the streams in this cycle are carefully worked out by the author. This second cycle, while much shorter than the first, extends over a vast period of time. It ended, as did the Cumberland, by a rise of the land and a slight

warping of the surface. The streams again began to adjust themselves to their new conditions, a work in which they are still engaged.

Hayes has made out the following changes which the streams have gone through in reaching their present courses. First, they moved westward to the interior sea as antecedent streams during the first cycle. Then they were diverted southward to consequent courses, and at last flowed westward as subsequent streams.

The way in which peneplains are correlated forms an interesting section of the paper. The types of stream basins as found in the region are vividly described. The maps, of which there are five, repay careful study.

F. H. H. C.

Geology of Minnesota, Final Report, Vol. IV. By N. H. WINCHELL, U. S. GRANT, WARREN UPHAM, and H. V. WINCHELL. Quarto, pp. i–xx, 1–630, with 31 geological maps, 48 photographic plates, and 114 figures. St. Paul, 1899.

This volume, which completes the areal geology of the state, follows its predecessors in the geographic arrangement of the subject-matter. The area covered embraces the northern third of the state, and includes some thirty counties and districts. The bed rock of the region, with the exception of scattered patches of Cretaceous, is almost universally crystalline in character, and is referred to the Archean and Taconic. The thickness of the drift is very great throughout most of the region considered, several counties in the northwestern part of the state presenting no outcrops whatever of the bed rock.

The crystalline rocks in this largely new field have naturally received much attention, resulting in the accumulation of a considerable mass of new facts relating to the Archean and Taconic, especially the former. The interpretations based upon these facts differ considerably from the commonly accepted views as to the character and divisions of the ancient crystalline rocks, and especially as to the assumed representative of the original crust of the earth.

It is to be regretted that the first presentation of a new classification should be somewhat lacking in clearness, but nowhere in the volume is there a satisfactory statement of the divisions into which the various clastic and igneous rocks of the state have been separated, nor of the equivalents in the ordinary classifications. As nearly as

may be judged from the report, the classification of the pre-Silurian rocks adopted by the survey is as follows:

Cambrian (St. Croix, "Potsdam")
(Upper Cambrian)

Taconic
(Lower Cambrian)
- Keweenawan
  - Potsdam (clastic) and Manitou (igneous)
  - . . . . . .
  - Cabotian (igneous)
- Animikie
- . . . . . .

Archean
- Upper Kewatin
- . . . . . .
- Lower Kewatin

I. ARCHEAN

1. *Lower Kewatin.*—The rock of the Lower Kewatin is in general designated by the survey as greenstone, and is composed of two divisions: (1) A lower massive igneous greenstone, assumed to represent the original crust of the earth, and (2) an upper series, partly fragmental and partly chemical, including beds of basic tuff, of agglomerate, and of conglomerate, the jaspilytes and iron ores of the Vermillion range, and vast masses of quartz-porphyry. Both the jaspilytes and the porphyry are tentatively held to be the result of chemical precipitation in the Archean ocean, the apparent dikes of the porphyry in the Upper Kewatin being considered as infolded masses, or as intrusions brought about by plasticity due to the subsequent application of heat and pressure.

2. *Upper Kewatin.*—The Upper Kewatin consists of a basal (Ogishke) conglomerate, overlaid by a series of graywackes, argillytes, and a single jaspilyte. The fragmental members are characterized by the presence in greater or less amounts of greenish material supposed to have been largely derived from the waste of the lower Kewatin, and from the Archean volcanoes. The whole series is involved with the Lower Kewatin in vertical isoclinal folds.

All the members of the Kewatin, both Lower and Upper, have been locally strongly metamorphosed, giving rise to clastic gneisses, schists, etc., where the action was simply one of recrystallization, and

to granites, syenites, diabase, gabbro, etc., where complete hydrothermal fusion took place.

II. TACONIC

This is considered as the time equivalent of the Lower Cambrian, and is separated from the Upper Kewatin by a marked unconformity. It is separated into two divisions, the Animikie and the Keweenawan.

1. *Animikie.*—The Animikie consists of a series of graywackes, slates, and quartzites, and the Mesabi iron ore series. The beds vary in dip from nearly horizontal to 45°. There are no known contemporary lava flows, but the rocks are characterized by the presence of numerous sills and dikes of diabase intruded during the interval separating the Animikie from the overlying clastics (Potsdam).

2. *Keweenawan.*—The clastic part of the Keweenawan is considered as Potsdam and is separated from the Animikie by a distinct unconformity. It begins with a basal conglomerate, usually red in color and of varying coarseness, known as the Puckwunge conglomerate, and is followed by quartzites and sandstones interbedded with lava flows of great volume and extent. The sedimentary beds became progressively thicker as the igneous activities waned, finally terminating in the white and siliceous sandstone of the overlying formation (Upper Cambrian). The dip is even more gentle than in the Animikie.

The eruptives of the Keweenawan are divided into two divisions, the Cabotian and the Manitou.

(*a*) *Cabotian.*—The Cabotian includes the great masses of gabbro, anorthosyte, diabase, etc., which in time of origin immediately antedate the Puckwunge conglomerate. In consequence of the great extrusion of igneous material, designated as the "great gabbro revolution," large areas of the Animikie were covered with heated lavas, resulting in the fusion of considerable portions of the former. Contemporary with this flow there were also important intrusions of gabbro as sills and dikes in the unfused portions of the series.

(*b*) *Manitou.*—The Manitou series is made up of a great number of surface flows, showing amygdaloidal and brecciated partings, and alternating with beds of sandstone in the upper portion. The first of the series appear as contemporaneous beds associated with the basal, or Puckwunge conglomerate, but the greater part of the eruptives are of a distinctly later date.

III. CAMBRIAN

The eruptives of the Manitou series gradually cease and give place to whiter and more siliceous sandstones, which in turn give way without any general break to the magnesian and argillaceous limestones of the Upper Cambrian. These Upper Cambrian rocks are of comparatively slight extent and importance in the area covered by the report.

Igneous rocks.—The igneous rocks, both acid and basic, of the Archean and Taconic are regarded as originating from the hydrothermal fusion of the older rocks, mostly from the clastics. The intermediate stages may often be seen.

The igneous rocks are of three classes—granites, diabases, and quartz-porphyries. The granites are of three relative ages, two being Archean and the third Taconic. They are referred to the fused portions of a still earlier acid clastic. The diabases are also of three relative dates, in this case one being in the Archean and two in the Taconic. They are believed to have been derived from the lowest greenstones, or to occur as apophyses of the gabbro, itself a secondary condition of the greenstone. The quartz-porphyry dikes are again of three periods, one each in the Lower and Upper Kewatin, and one cutting portions of the Taconic. They are supposed to have been derived from the great quartz-porphyry mass of the Lower Kewatin, or from some later clastic.

Glacial Geology.—Besides the mass of observations relating to the crystalline rocks, there are a considerable number relating to the glacial geology of the northern portion of the state, but these observations are not systematically discussed with reference to the great problems of glacial geology.

The thirty or more maps included in the report give, in addition to the geology and ordinary topographic features, approximate contours for every fifty feet, which adds greatly to their usefulness and value. The maps are pleasingly colored and neatly executed. The volume is profusely illustrated by photographic reproductions and line cuts. The former, especially, are numerous, and though not always what might be desired in the point of clearness and appropriateness, add materially to the attractiveness and value of the report.

As one reads the report he cannot but be impressed by the great number of observations made and the mass of facts accumulated, but the disconnected and unsystematic manner of presentation, which necessarily follows from the geographical treatment adhered to

throughout the volume, detracts greatly from the value they would otherwise possess. Too much is left to be inferred, and there is always a strong liability of error in the putting together of scattered observations from various localities which the reader is obliged to do for himself in order to obtain an intelligent understanding of the questions treated.

It is proposed in the next volume of the Final Report (Vol. V), nearly half of which is already in type, to take up the systematic geology of the state, and many of the details, upon which are based the extensive changes of classification and the new conclusions regarding the problems of archean geology, are reserved for publication in this volume. It seems better, therefore, to reserve any extended criticism of the proposed changes until the full facts upon which they are based are published. M. L. FULLER.

The Ore Deposits of the United States and Canada. By JAMES F. KEMP, New York, 1900, 3d edition, rewritten and enlarged. xxiv + 481 pp. 163 illustrations.

It is with pleasure that geologists will welcome the new edition of Professor Kemp's work on ore deposits. It is to be noticed that the revision has been so complete and the additions so numerous as to bring the matter up to the date of publication and make it one of the most valuable works of its kind in this country.

Professor Kemp has undertaken a difficult task in endeavoring to embody in a single volume a serviceable text-book and a work of reference. That he has succeeded is shown in the first instance by its increased use in the colleges and in the second by a perusal of its pages.

The general plan of the work remains about the same as in the former editions. The matter is divided into two parts, the first o which treats of the general features of ore deposits, the underlying geological principles, the minerals important as ores, the gangue minerals, and their sources, the structural features of veins, the filling of veins, and the classification of ore deposits. This part of the work would have additional value, especially to the prospector and engineer, if it were illustrated a little more fully by diagrams. It is true the number of illustrations has been increased from 94 to 163, but there is

still room for more in the first part even though it should be at the expense of some of the excellent half-tones in the second part.

Part II treats of the ore deposits in detail, taking up the metals one by one, beginning with the more common useful metals, as iron, copper, lead and zinc, followed by the precious metals, silver and gold, and closing with the lesser metals. The most important of these, iron and gold, are treated more fully than the others and it is here we find the greatest changes in the new edition. This portion consists largely of a well arranged and classified review of the best literature on each locality, all the more valuable to the investigator because specific references to the original sources of information are given, thus making it a handbook and manual of reference. Field studies and personal observations in many of the leading mining centers have enabled the author not only to present the most salient features, but to supplement this from his own notes.

The features of the new edition that show the most marked changes are as follows: (1) The Lake Superior iron district is completely revised to accord with the enormous developments which have taken place; (2) the part on limonite ores has been expanded; (3) the Butte district has a new description and maps based on the excellent folio of the United States Geological Survey; (4) the same is true of the Cripple Creek and other districts in Colorado; (5) the part on the gold deposits of the southeastern states has been rewritten and enlarged; (6) a description of the Canadian mining districts, which did not appear in former editions, has been added.

T. C. H.

The Fauna of the Chonopectus Sandstone at Burlington, Iowa. By STUART WELLER. Trans. St. Louis Acad. Science, Vol. X, No. 3, pp. 57–129. Plates I–IX. Feb. 1900.

In his series of Kinderhook faunal studies, of which the present paper is the second,[1] Mr. Weller is doing a much-needed work of revision. The rocks now classed as Kinderhook mark the border line between the Devonian and the Carboniferous over an important portion of the Mississippi valley. They were, by the earlier workers, referred at times to both periods, and there was much dispute as to their proper classification and correlation. Finally Meek and Worthen

[1] For first see Trans. St. Louis Acad. Sci., IX, No. 2., pp. 9–51.

proposed the term Kinderhook to cover the beds, and named the Burlington, Iowa, section for one of the three type sections. The best known collection of fossils from Burlington has been that belonging to the University of Michigan, and known commonly as the "White collection." Descriptions of the fossils in this have been published by C. A. White, C. A. White and R. P. Whitfield, and by A. Winchell, and these descriptions have been the ones principally used heretofore in studying Kinderhook species. The descriptions were, however, in many cases unsatisfactory, and were seriously limited in usefulness by the fact that many of the species were not figured. Under the circumstances it is not surprising that the early doubts as to the age and divisions of the Kinderhook have not been altogether cleared away. Mr. Weller has made careful use of the original White and other collections, and has supplemented his data by notes and specimens taken at Burlington. He has found that the Kinderhook includes seven distinct faunal zones, and in the series of papers now being published he is describing and figuring the fossils from these individual zones. It proves that certain of them have strong Devonian affinities, while others are to be assigned to the Carboniferous. Much of the confusion has come from the failure to distinguish the individual bed from which the species were collected. In the case of the Chonopectus sandstone the brachiopods are, for the most part, strongly Carboniferous in aspect. The pelecypods, gasteropods, and cephalopods, are predominantly Devonian as is the larger number of the total of 81 species recognized. The author regards this, however, as a probable instance of the persistance into Carboniferous time of certain favored Devonian forms. The other view, that these are the earliest and initiatory Carboniferous forms appearing in time properly Devonian, is not, however, as yet, excluded.

As a whole the paper is one of wide interest and value, and will prove very suggestive and useful.

H. F. B.

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